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Stinger Team Performance During Engagement Operations in a Chemical Environment: The Effect of Cuing

David M. Johnson and Joan Dietrich Silver
U.S. Army Research Institute

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For this report, 29 Stinger teams were tested wearing chemical protective clothing under conditions of MOPP0 (Mission Oriented Protective Posture 0) and MOPP4 in the Range Target System engagement simulation facility. Twelve teams performed without precise cuing information, and 17 performed with precise cuing information. Measurements were recorded for engagement performance, stress, workload, and vision. Engagement performance was degraded by wearing MOPP4, but was improved with the addition of precise visual cues. Use of these cues substantially reduced the degradation from wearing MOPP4. For rotary-wing targets, cues restored 53% of the engagement time lost to MOPP4. For fixed-wing targets, cues restored engagement ranges to MOPP0 levels. Reported stress and workload ratings were higher for MOPP4 than for MOPP0. Detection performance of Stinger team chiefs, both in MOPP0 and MOPP4, was correlated with several measures of visual sensitivity.

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Stinger Team Performance During Engagement Operations in a Chemical Environment: The Effect of Cuing

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FOREWORD

This report discusses research performed by the Soldier-System Effectiveness Team of the Fort Bliss Field Unit of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI). The mission of this team is to perform research and development in human performance issues relevant to Army Air Defense effectiveness. Field tests have shown that the engagement performance of Stinger teams is impaired by wearing MOPP4 (Mission Oriented Protective Posture 4) chemical protective clothing. The objective of the research reported here was (1) to quantify the magnitude of this performance decrement using a MOPP0 control condition and (2) to determine the extent to which this performance decrement could be alleviated by adding accurate cuing information.

This research is part of a larger team project entitled "Forward Area Air Defense Performance During Engagement Operations in a Chemical Environment," which is funded by the Physiological and Psychological Effects of the Nuclear, Biological, and Chemical Environment and Sustained Operations on Systems in Combat (P^2NBC^2) program administered by the U.S. Army Chemical School at Fort McClellan. The proponent agency for this research is the Directorate of Combat Developments at the U.S. Army Air Defense Artillery School (USAADASCH) at Fort Bliss, Texas. A Memorandum of Agreement covering this research project was signed on 7 November 1991 by USAADASCH and ARI.

The results of this research were briefed to Colonel Schnakenberg, Chairman, and members of the P^2NBC^2 Technical and Scientific Advisory Group on 16 January 1992. The final test report describing this research was evaluated by the proponent in an Abbreviated Operational Assessment (AOA) memorandum dated 17 January 1992. This AOA concurred with the results described in the final test report.

EDGAR M. JOHNSON
Technical Director

STINGER TEAM PERFORMANCE DURING ENGAGEMENT OPERATIONS IN A CHEMICAL ENVIRONMENT: THE EFFECT OF CUING

EXECUTIVE SUMMARY

Requirement:

This research was performed to quantify the extent to which Stinger team performance is degraded during engagement operations while MOPP4 (Mission Oriented Protective Posture 4) chemical protective clothing is worn and to determine if precise visual cuing information will reduce this degradation.

Procedure:

Twenty-nine Stinger teams of two members each (team chief, gunner) were tested under conditions of MOPP0 and MOPP4 in the Range Target System engagement simulation facility. Twelve teams performed without precise cuing information, and 17 performed with precise cuing information. Measurements were recorded for engagement performance, stress, workload, and vision.

Findings:

The engagement performance of Stinger teams was significantly poorer when wearing MOPP4 than when wearing MOPP0. This decrement in performance occurred for both fixed-wing targets and rotary-wing targets. Analysis of these results suggests that the performance degradation seen in MOPP4 was attributable to the properties of the gas mask: Engagement performance was significantly better for the cued teams than it was for the teams that were not cued. This improvement was seen both for fixed-wing and rotary-wing targets. Use of cues substantially reduced the degradation attributed to wearing MOPP4. For rotary-wing targets, cues restored 53% of the engagement time lost to MOPP4. For fixed-wing targets, the cues restored engagement ranges back to MOPP0 levels. Reported stress and workload ratings were significantly higher when Stinger teams wore MOPP4 than when they wore MOPP0. The detection performance of Stinger team chiefs, both in MOPP0 and in MOPP4, was significantly correlated with several measures of visual sensitivity.

Utilization of Findings:

The results of this research, in the form of a final test report complete with data, were provided to the funding organization (the Physiological and Psychological Effects of the Nuclear, Biological, and Chemical Environment and Sustained Operations on Systems in Combat Program administered by the U.S. Army Chemical School) for inclusion in its reference library and Performance Assessment Model, which will be implemented throughout the Army.

STINGER TEAM PERFORMANCE DURING ENGAGEMENT OPERATIONS IN A CHEMICAL ENVIRONMENT: THE EFFECT OF CUING

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STINGER TEAM PERFORMANCE DURING ENGAGEMENT OPERATIONS IN A CHEMICAL ENVIRONMENT: THE EFFECT OF CUING

Background

The deleterious effects of wearing the Mission Oriented Protective Posture (MOPP) ensemble on performance are well documented. A review of literature showing the degrading effects of MOPP gear on performance was conducted by Carr, Corona, Jackson, and Bachovchin (1980), and Carr, Kershner, Corona, and Jackson (1980). The review focused on ten tests of military personnel conducted over a twenty-year period (1959-1979). Participants in the studies included mechanized rifle companies, armor crews, artillery crews, aviators, and maintainers performing their assigned duties. In most cases, the MOPP4 ensemble significantly impaired the ability of the soldiers to execute their assignments.

For instance, artillery and mortar forward observers experienced a decrement when performing target detection and fire adjustment, and a Reinforced Mechanized Rifle Company's ability to execute a dismount maneuver was unacceptably degraded. Maintenance elements experienced a decrement when performing support tasks in full MOPP, and a Marine Battalion Landing Team was totally incapable of executing an amphibious assault in the chemical protective ensemble. Performance degradation was also experienced by aviators executing attack, defense, and fire missions as well as by the staff of a Tactical Operations Center (TOC) performing routine actions during a seven-day command-post exercise. Most functions performed by the TOC staff were slower in MOPP4, and written work and communications by radio and telephone were subject to more errors.

Although degradation was investigated across a variety of tasks using diverse military personnel, several factors that can affect performance in MOPP gear were not examined. For instance, the studies cited in the review were conducted in temperate climates. Therefore, excessive heat was not a factor in performance degradation because none of the temperatures ranged over 90 degrees Fahrenheit. The effect of cold weather and MOPP gear on performance was not examined in any of the tests. The studies, which were conducted at the squad, platoon, and company level, did not include mountainous, jungle, or desert terrains. Female participants were not involved in the research.

Evidence of the detrimental effects of the MOPP4 ensemble continues to be documented. The literature from 1980 to 1988 dealing with the effects of the chemical defense ensemble and extended operations on performance was summarized by Headley, Brecht-Clark, Feng, and Whittenburg (1988). Their review included mostly laboratory and small-scale field tests involving infantry performing tasks in temperate climates and moderate terrains.

Headley et al. (1988) reported that performance in MOPP gear is a function of many variables interacting with each other. Performance degradation can be influenced by ambient temperature, amount of activity involved, previous training in MOPP gear, type of task, skills required to perform the task, and amount of rest or fatigue.

Based on their review of studies in which the chemical protective ensemble was used, Headley et al. (1988) reached several conclusions. They determined that communication in MOPP gear can be difficult, and that this difficulty is exacerbated by distance and noise. The authors observed that soldiers will devise new ways to perform their tasks to overcome the effects of the chemical protective ensemble and concluded that training in MOPP gear is essential to prevent soldiers from using the battlefield as a place to improvise ways to carry out their duties. It was further demonstrated in the reviewed studies that practice in MOPP gear can reduce some performance decrements, specifically those associated with fine motor skills. It was also shown that high ambient temperatures lead to levels of discomfort intense enough to cause performance decline on most tasks. Ultimately, according to Headley et al., most tasks can be performed in the MOPP ensemble, but completion times may be longer.

The performance decrements in MOPP4 described in the literature reviews can result from a variety of factors such as loss of manual dexterity, degradation of reaction time, deterioration of psychomotor skills, impairment of speech intelligibility, and reduction of the visual field. These variables are being investigated to disclose the degree of decrement specific to a given situation. In some cases, a particular piece of the MOPP ensemble is directly and often times solely responsible for the observed performance decrement. The mask and hood worn as part of the MOPP gear, for instance, are known to degrade vision and speech functions.

Reduction of the field of view as a function of the chemical protective mask has been examined in laboratory settings by Bensel, Teixeira, and Kaplan (1987), Harrah (1985), and Kobrick and Sleeper (1986). Harrah examined visual performance using three prototype XM40 protective masks in combination with M19 binoculars. Targets were presented to the participants on slides. Harrah recorded the field of view with each binocular-mask combination and the standoff distance from the soldier's eye to the mask lens to explore their relationship to scan time performance. He found that mean field of view decreased linearly as standoff distance increased. The decreased field of view caused an increase in the time required to scan the target area.

Kobrick and Sleeper (1986) examined impairment of the visual field by studying the effect of wearing MOPP4 in a hot environment on signal detection. Participants performed a target detection task which required them to depress a hand-held push-button switch whenever the onset of a signal light was detected. The authors found that response time for signal detection increased systematically and significantly with peripheralization of stimulus locations. Visual impairment occurred early during the test and remained at that level for the rest of the day. The authors concluded that the effects of MOPP gear upon visual performance are significant and serious.

Bensel et al. (1987) quantified the field of view decrement caused by wearing the chemical protective ensemble mask. The male soldiers participating in this experiment were instructed to depress a switch upon initial detection of a target light. Both eyes were tested monocularly over ten areas of the visual field. Bensel, et al. found that the mask substantially restricted the field of view when compared to bareheaded performance.

The laboratory setting has also been used to examine the effects of the chemical protective ensemble mask on speech intelligibility. Bensel, et al. (1987) used the M17A1 mask and the Modified Rhyme Test to examine speech intelligibility and found that performance in the MOPP4 condition was degraded when compared to the no MOPP condition. A speech intelligibility performance decrement in the MOPP4 ensemble was also found by Nixon and Decker (1985). Paid volunteers were tested in the All-Purpose MCU-2 chemical protective mask. The Modified Rhyme Test was used. The MCU-2 mask and hood exhibited good speech intelligibility for all communication configurations in the 77dB ambient and environmental noise condition. However, voice communication was not satisfactory for personnel wearing the mask and hood under the same communication situations in the higher levels of simulated operation noise, such as those which would be experienced in combat.

Elements of the MOPP4 ensemble (suit, gloves, boots, and mask) can act alone or in concert to impede body mobility, psychomotor coordination, and manual dexterity. While gloves generally make the greatest contribution to performance decrement for tests of manual dexterity (Bensel, 1980; Bensel, et al., 1987; Johnson & Sleeper, 1986), reduced body mobility and impeded psychomotor coordination can result from various combinations of the components of the protective ensemble (Bensel, et al., 1987).

Although serious problems are associated with wearing MOPP gear, the effects of the chemical protective ensemble are differential depending upon the task being performed. Many studies have shown MOPP0 and MOPP4 performance to be functionally equivalent. They have also shown that even though MOPP4 performance is degraded, in many cases it is still well within military standards.

As examples, Posen, Munro, Mitchell, and Satterthwaite (1986) subjected M113 and Bradley Infantry Fighting Vehicle squads to over 60 hours in near continuous MOPP4 and found no significant performance degradation. Similarly the U.S. Air Force Tactical Warfare Center (1981) found that a random sample of currently qualified security police could also meet standards using the M-60 machine gun and M-16 rifle while wearing chemical defense equipment. Eighty percent of the sample using the M-16 rifle attained qualifying scores and 100 percent of those in the sample using the M-60 attained qualifying scores. Even though Glumm (1988) reported a performance decrement when testing armor crews under nuclear, biological, and chemical (NBC) conditions for up to 72 continuous hours, the degradation was not significant. Although over time, the number of targets that these crews attempted to engage decreased and engagement time increased, the crews hit 99 percent of their engaged targets. Glumm observed no substantial performance decrement in gross or overlearned tasks such as ammunition resupply, vehicle or aircraft identification, and weapon assembly or disassembly. Also there was no evidence of a serious performance degradation on these latter tasks over time.

Even in the situations in which substantial performance decrements do not occur while wearing the MOPP4 ensemble, serious concerns about the health and safety of the participants may exist. Wearing MOPP gear in hot environments subjects the participant to the very real and dangerous possibility of heat stress, heat stroke, and dehydration. Medical monitoring of participants (Knox, Simmons, Christiansen, & Siering, 1987; Mitchell, Knox, & Wehrly, 1987; Posen, et al., 1986) via rectal temperature probes, body weight, urine specimens, EKGs, and EEGs, however, has made it possible to establish criteria by which participants should be withdrawn from a MOPP4 investigation.

Interestingly, there are studies in which a MOPP performance decrement has not been noted and in which differences in physiological measures have not occurred as a function of the chemical protective ensemble (Heslegrave, Frim, Bossi, & Popplow, 1990; Posen, et al., 1986) but in which measures have indicated the presence of psychological impairment. Heslegrave, et al. found that CF-18 pilots in full individual protective equipment (IPE) retained their operational effectiveness and showed little objective evidence of degraded efficiency or safety. The pilots in this research were capable of flying their aircraft and completing their missions. Although some performance and physiological degradation was noted, objective flight performance information, objective physiological measures, and objective cognitive tests failed to indicate significant degradation. However, the IPE pilots reported subjectively increased levels of fatigue, deterioration in mood, and flight performance impairment on some missions, thus demonstrating the psychological impact of the protective ensemble.

Posen, et al., investigating Mechanized Infantry soldiers and squads, also reported no significant differences in terms of performance degradation or physiological measures between MOPP1 and MOPP4 conditions in a mild to moderate climate. However, after 60 or more hours in near continuous MOPP4, psychological measures revealed increases in respiratory distress and decreases in clear thinking and friendliness. This finding demonstrates again that even in the absence of significant performance and physiological decrements, psychological impairment can occur. It remains to be seen how this impairment may ultimately impact performance, if at all.

Because the effects of the chemical protective ensemble are differential in terms of performance degradation, physiological measures, and psychological impairment, it is necessary to establish the consequences of MOPP gear across tasks. Currently, insufficient data exist to allow prediction of tasks which will be impaired by MOPP4 gear. On 9 May 1984 the Army Vice Chief of Staff directed that a program be initiated to assess the Physiological and Psychological Effects of the Nuclear, Biological, and Chemical Environment and Sustained Operations on Systems in Combat (P^2NBC^2). This directive followed from the Airland Battle doctrine requirement for extended operations on a battlefield where NBC agents are habitually employed and was targeted to ensure that the combined arms forces are prepared to fight and win on this integrated battlefield.

Initial tests under the P^2NBC^2 program are establishing a baseline for crew performance to allow examination and validation of remedial measures. Results of these tests are being used to provide planning and operational risk factor analyses to field commanders, to support the development of training programs, to develop doctrine and organization, and to influence the design and acquisition of materiel to improve the capability to conduct successful combat operations on a battlefield where NBC weapons are extensively and continuously employed. Concurrent and complementary research is identifying, compiling, and assimilating information to guide and supplement this process.

This paper reports the results of research conducted under the auspices of the P^2NBC^2 program. The investigation addressed P^2NBC^2 issues of performance degradation and psychological effects of the chemically contaminated environment by testing Forward Area Air Defense (FAAD) soldiers in MOPP0 and MOPP4 under benign environmental conditions. Two sub-experiments were conducted. In Sub-Experiment 1, baseline data were collected for the purpose of quantifying the performance decrement which was predicted to occur during FAAD engagement performance when the MOPP4 chemical protective ensemble is worn. It was hypothesized that the MOPP4 mask in particular would reduce the field of view sufficiently to cause a significant performance decrement.

Sub-Experiment 2 replicated the conditions of Sub-Experiment 1 and in addition contained a procedure through which the performance decrement seen in the baseline experiment was expected to be alleviated. Because the chemical protective ensemble mask restricted the field of view of FAAD soldiers, it was hypothesized that by providing precise cues as to type, range, number, and azimuth of approaching aircraft the performance decrement observed during Sub-Experiment 1 would be reduced.

Stress and workload scales were administered during both sub-experiments to address the psychological effects of the chemical protective ensemble. Participants in this research were requested to respond to a stress questionnaire by indicating the feelings they were experiencing at that particular moment in time. It was predicted that perceived stress would be greater under conditions of MOPP4. Workload measures were collected after each trial for record. Respondents rated the degree of workload they had experienced on the preceding trial along six dimensions. Workload was predicted to be significantly higher when the chemical protective ensemble was worn.

This investigation also addressed visual correlates of FAAD engagement performance. Although this question is not specifically aligned with P^2NBC^2 issues, previous research (Barber, 1990a) has demonstrated that certain measures of visual sensitivity are related to air defense engagement performance.

Method

Participants

Sub-Experiment 1. Twelve Stinger teams from the 1st Battalion, 56th Air Defense Artillery Regiment served in this sub-experiment during December of 1990. Each team consisted of two soldiers, a team chief and a gunner. The Military Occupational Specialty (MOS) for all soldiers was 16S. The mean age of soldiers was 19.0 years (median 18.0). All 24 participants were in their last week of Advanced Individual Training (AIT) at Fort Bliss, Texas.

Sub-Experiment 2. Seventeen Stinger teams from the 1st Battalion, 56th Air Defense Artillery Regiment, served in this sub-experiment during January of 1991. Each team consisted of two soldiers, a team chief and a gunner. The MOS for all soldiers was 16S. The mean age of soldiers was 21.6 years (median 20.0). All 34 participants were in their last week of AIT at Fort Bliss, Texas.

The Stinger Weapon

Stinger is a man-portable air defense weapon system. It is a shoulder-fired, infrared-homing (heat-seeking) guided missile. Stinger requires no control from the gunner after firing. It has an identification friend or foe (IFF) subsystem which electronically interrogates target aircraft to establish friendly identification. Stinger provides short-range air defense for maneuver units and less mobile combat support units. Stinger is designed to counter high-speed, low-level, ground-attack aircraft. It is also effective against helicopter, observation, and transport aircraft (Field Manual No. 44-18-1, 1984).

Gunners maintain proficiency by practicing with the Stinger Training Set Guided Missile (M134). Each training set consists of a tracking head trainer, five rechargeable batteries, an IFF simulator, and a storage container. The Stinger tracking head trainer (THT) simulates the actual live Stinger round in size, shape, weight, and feedback from engagement actions—except, of course, no missile is launched. The seeker head inside the THT is the same seeker head as inside the live missile. Thus, its audio feedback to the gunner while tracking the heat source of an aircraft is the same. The IFF simulator imitates the actual IFF subsystem in size, weight, cabling requirements, and provides the same audio feedback to the gunner. The Training Set Guided Missile was the weapon used during this research. Two were used in Sub-Experiment 1 and four were used in Sub-Experiment 2.

Additional Equipment

Additional equipment included 7 x 50 binoculars (M19), one pair for each team chief. Except for the M40 mask and hood, all MOPP4 equipment was provided by the unit supplying the participants. This included the overgarment (worn closed), the overboots, and the gloves. The mask and hood were also worn closed.

The Range Target System (RTS)

Description. Air defense performance data for this experiment were collected in the Range Target System (RTS). RTS is a Forward Area Air Defense engagement simulation facility. In this simulation facility, air defenders employ their actual weapons in simulated engagement of subscale fixed-wing and rotary-wing aircraft. RTS is located in the desert near Condron Army Airfield at White Sands Missile Range, New Mexico. RTS is the third FAAD simulation facility developed by the United States Army Research Institute (USARI) Fort Bliss Field Unit, having evolved from the Realistic Air Defense Engagement System (RADES) circa 1984-1985, and the multiple weapon RADES (MRADES) circa 1986-1989. RTS has been operational since 1989. Details as to the validation of this simulation facility can be found elsewhere (Barber, 1990b; Drewfs, Barber, Johnson, & Frederickson, 1988; Johnson, Barber, & Lockhart, 1988).

RTS was designed to be a high-fidelity, non-system-specific testbed, trainer, and evaluator for the current FAAD weapon systems [Vulcan, Product Improved Vulcan Air Defense System (PIVADS), Chaparral, Stinger, and Avenger]. As such, RTS can address the crew engagement training requirements for over half the air defense population (MOSs 16R, 16P, 16S, and 14S). Unlike the two previous designs, RTS is mobile and can be set-up relatively quickly for new training exercises or test applications. Its modular design makes it versatile, allowing RTS to be rapidly reconfigured to meet the specific needs of commanders, trainers, or evaluators. To date, Vulcan, PIVADS, Chaparral, Stinger, and Avenger units have engaged aircraft in RTS.

RTS currently uses one-fifth scale rotary-wing (helicopter) and fixed-wing (airplane) targets, although other scales can be accomdated and have been used in the past. All targets represent US or Soviet aircraft. Aircraft are camouflaged, three dimensional, molded fiberglass replicas. They are either flown remotely according to prescribed flight paths and maneuvers, or pop-up from designated positions via pneumatic stand-lift mechanisms. The flying fixed-wing (FW) and rotary-wing (RW) aircraft are remotely controlled by radio signals from expert pilots stationed in the test range. The pop-up RW targets are positioned strategically behind sand dunes at scenario prescribed distances. Flying aircraft are tracked by a laser position-location system which is accurate to within one meter in three dimensional space. All aircraft are fitted with a heat source which stimulates the infrared-radiation seeker of heat-acquiring missile systems such as Chaparral, Stinger, and Avenger.

Air defense weapons are transported to the RTS site and emplaced in a battle position. Weapons are cabled to the Data Acquisition Station (DAS) and signal taps are installed on key weapon pins. The DAS interrogates the weapon every 250 milliseconds to see if a gunner action has occurred. Gunner engagement actions are thus collected automatically and time coded with a resolution of 250 milliseconds. Team chief verbal actions, such as detection and identification, are recorded by a human data collector who enters keystrokes on a computer keyboard located at the weapon position. The DAS interrogates this keyboard every 250 milliseconds to see if a verbal action has occurred. In this fashion gunner and team chief engagement actions are entered into the trial database along with a time code—time in seconds from target availability—and a range code—range of target aircraft in kilometers from fire unit. Thus, at the end of each engagement trial a complete record of all engagement actions emitted by the team is obtained. This record is mathematically processed in near real time and is available in the form of feedback a few seconds after the termination of each scenario trial.

For gun systems, such as Vulcan or PIVADS, a laser ballistics simulation module is interfaced with the turret electronics and boresighted to the barrels. This part of the RTS simulation records where the gunner is pointing relative to the known position of the target and upon fire a mathematical model synthetically flies each round out to target intercept (or miss) in real time. The simulator provides a display of red tracer rounds in the gunner's reticle which appear where actual rounds would appear. This simulator provides specific performance feedback in the form of number of rounds on target, mean miss distance, and direction off center. For missile systems, the mathematical model synthetically flies each missile out to known target position for target intercept (or miss) in real time. Of course, RTS has a different mathematical model for each different missile system and ammunition type. In this fashion the effects of a complete engagement can be determined ("kill" or "miss") without necessitating the dangers or expense of live fire.

The primary components of the Range Target System are the Flying Target System (FTS), the Pop-Up Target System (PTS), the Range Control Station (RCS), the Data Acquisition Station (DAS), and the Position Location Station (PLS). The RCS, DAS, and PLS components are described in greater detail in Barber (1990c). The PTS and FTS components, respectively, are described more fully in Berry and Barber (1990a&b).

The FTS presents flying, one-fifth scale models of fixed-wing and rotary-wing aircraft. Current models include the US A-7, A-10, and F-16 as well as the Soviet Su-17, Su-25, and MiG-27. [NOTE: FTS is capable of providing a valid target environment with scales other than one-fifth. In order to reduce costs in this experiment, FTS presented one-seventh scale FW aircraft from an earlier inventory. These were aircraft that USARI had purchased previously. The specific models were the US A-7 and A-10, as well as the Soviet Su-20/22 and Su-25.]

The PTS presents one-fifth scale models of rotary-wing aircraft. These helicopters pop-up, pneumatically, from defilade, hover for a scenario-specified period of time with the rotor turning, and then descend. Each PTS is computer controlled by radio-frequency instructions sent from the RCS. Current models include the US AH-1, AH-64, UH-1, UH-60, and CH-3 as well as the Soviet Mi-8, Mi-24, and Mi-28. The models used in this experiment were the AH-1, AH-64, UH-1, Mi-8, Mi-24, and Mi-28.

The RCS is the station where voice communications, system test and calibration checks, initialization of the system, real-time functions, performance scoring, and printing of feedback are initiated. Control of the Range Target System during scenario presentation is located at the RCS. The RCS software is designed to link with up to eight Data Acquisition Stations and to control up to twelve Pop-Up Target Systems.

The DAS captures all of the squad leader (or team chief) and gunner engagement task performance and weapon events as a function of elapsed time and aircraft range. Response time is measured with a resolution of 250 milliseconds. Aircraft range is measured using the Position Location System to a resolution of one meter. Effects scoring and assessment of kills are also performed at the DAS. The DAS provides scenario feedback on these events.

During Sub-Experiment 1 there were two separated weapon positions, each with its own DAS and data collector. During Sub-Experiment 2 there were four separated weapon positions each with DAS and data collector. (Not all four weapon positions were used on every test day, depending upon soldier availability.) Currently, all DASs are controlled by the RCS and communicate with the RCS by radio frequency signals. Prior to each trial, scenario information is down-loaded from RCS to DAS. After each trial, engagement data are up-loaded from DAS to RCS.

The PLS is used for two key purposes. First, it is used to register (ground locate) the weapon, the pop-up helicopter stands, flying target launch positions, as well as the other RTS stations (RCS, DAS, and PLS). Second, it is used to track flyable targets and determine their range throughout a scenario. The PLS can automatically detect, acquire, and track flyable targets. It can also be operated manually using its video display and trackball.

Measures of performance obtained from RTS. Two general classes of performance measures were collected—Task Performance Measures and Summary Performance Measures. Task Performance Measures (TPMs) are potentially collectable on a trial-by-trial basis. These measures describe the time elapsed or the target aircraft range when specific engagement actions (tasks) are performed. For fixed-wing aircraft these TPMs are expressed in terms of the aircraft range in full-scale kilometers when the engagement actions occurred (e.g., detection range, identification range, fire range). Since RTS aircraft are subscale, all ranges are presented in terms of full-scale range equivalents by multiplying the measured range by the scaling factor. For rotary-wing aircraft TPMs are expressed in terms of the elapsed time, in seconds, between two events or engagement actions (e.g., time from target available to detect, time from detect to identify, time from identify to fire). The TPMs collected in this experiment are described in Table 1 by aircraft type.

Summary Performance Measures (SPMs) are collected by summing across appropriate scenarios. SPMs are expressed in terms of percentages (e.g., percent aircraft detected, percent hostile aircraft correctly identified, percent hostile aircraft attrition). The SPMs collected in this experiment are described in Table 2.

Procedure

Data collection activities took place in two phases—those activities performed prior to field testing and those activities performed during field testing. Field testing took place during four three-day periods (Saturday, Sunday, and Monday) in December 1990 and January 1991. Vision testing and related activities took place each Wednesday and Thursday evening immediately prior to the field testing. Half of the soldiers due for field testing the following weekend were brought in for vision testing on Wednesday evening and the remaining half on Thursday evening. The schedule of data collection activities is presented in Table 3.

Table 1

Task Performance Measures Obtained fr... RTS by Aircraft Type

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Fixed-Wing Aircraft

Detection Range: Range of aircraft in full-scale kilometers at detect response ("target")

Identification Range: Range of aircraft in full-scale kilometers at ID response (tactical ID "hostile" or "friendly")

IFF Range: Range of aircraft in full-scale kilometers at IFF button push

Acquire Range: Range of aircraft in full-scale kilometers at weapon acquisition signal

Lock-On Range: Range of aircraft in full-scale kilometers at press of uncage bar (which locks seeker onto target)

Fire Range: Range of aircraft in full-scale kilometers at fire trigger pull

Percent Tracking Time on Target: Percent of total time window between first weapon acquire signal and press of uncage bar that weapon is signaling acquire (i.e., time on target divided by total possible tracking time)

Rotary-Wing Aircraft

Time from Target Available to Detect: Time in seconds from instrument record of target available until detect response (target available is defined as that time when the target has risen far enough to be visible from the weapon positions)

Time from Detect to IFF: Time from detect response to IFF button push

Time from Detect to Identify: Time from detect response to ID response

Time from Detect to Acquire: Time from detect response to weapon acquisition signal

Time from Acquire to Lock-On: Time from weapon acquire signal to press of uncage bar

Time from Lock-On to Fire: Time from press of uncage bar to fire trigger pull

Time from Identify to Fire: Time from ID response to fire trigger pull

Time from Detect to Fire: Time from detect response to fire trigger pull

Table 2

Summary Performance Measures Obtained from RTS

Percent Aircraft Detected: Number of aircraft for which a detect response is given, divided by the total number of aircraft presented

Percent Aircraft Correctly Identified: Number of aircraft for which a correct ID response is given, divided by the total number of aircraft detected

Percent Hostile Aircraft Correctly Identified: Number of hostile aircraft for which a correct ID response is given, divided by the total number of hostile aircraft detected

Percent Friendly Aircraft Correctly Identified: Number of friendly aircraft for which a correct ID response is given, divided by the total number of friendly aircraft detected

Percent Hostile Attrition: Number of hostile aircraft credited as killed, divided by the total number of hostile aircraft presented

Percent Fratricide: Number of friendly aircraft credited as killed, divided by the total number of friendly aircraft presented

Percent Hostiles Killed Prior to Ordnance Release: Number of hostile aircraft credited as killed prior to ordnance release, divided by the total number of hostile aircraft presented (Ordnance release is defined as approaching within two kilometers of weapon position for fixed-wing aircraft. Ordnance release is defined as 20 seconds after target availability for rotary-wing aircraft.)

Conditional Probability of Kill Given Fire (expressed in percent): Number of aircraft credited as killed (hostile plus friendly), divided by the total number of fire events (fire trigger pulls)

Table 3

Schedule of Data Collection Activities

Sub-Experiment 1: Stinger Baseline

	Wed	Thu	Sat	Sun	Mon
	5 Dec	6 Dec	8 Dec	9 Dec	10 Dec
AM:	- - -	- - -	MOPP0	MOPP4	MOPP0
PM:	- - -	- - -	MOPP4	MOPP0	MOPP4
Night:	Vision	Vision	- - -	- - -	- - -
	12 Dec	13 Dec	15 Dec	16 Dec	17 Dec
AM:	- - -	- - -	MOPP4	MOPP0	MOPP4
PM:	- - -	- - -	MOPP0	MOPP4	MOPP0
Night:	Vision	Vision	- - -	- - -	- - -

Sub-Experiment 2: Stinger Cuing

	Wed	Thu	Sat	Sun	Mon
	16 Jan	17 Jan	19 Jan	20 Jan	21 Jan
AM:	- - -	- - -	MOPP0	MOPP4	*
PM:	- - -	- - -	MOPP4	MOPP0	*
Night:	Vision	Vision	- - -	- - -	- - -
	23 Jan	24 Jan	26 Jan	27 Jan	28 Jan
AM:	- - -	- - -	MOPP0	MOPP4	MOPP0
PM:	- - -	- - -	MOPP4	MOPP0	MOPP4
Night:	Vision	Vision	- - -	- - -	- - -

AM = 0900-1200 hrs
PM = 1300-1600 hrs
Night = 1800-2100 hrs
* = Cancelled due to snowstorm

Activities prior to field testing. USARI personnel transported the research participants to Building 111, Fort Bliss, home of the USARI Fort Bliss Field Unit. Here the soldiers were briefed as to the nature of the research and their participation in it. Information concerning the weekend field testing was kept at a general level. Information concerning the night's vision testing was described in detail. Questions were answered, where appropriate. Soldiers were offered the opportunity to read and then sign the Volunteer Affidavit. All signed. Participants were then tested individually for foveal visual acuity, visual contrast sensitivity, and visual resting focus distance.

Foveal visual acuity was measured binocularly from a distance of 20 feet (6.10 meters) using the standard Tumbling-E acuity chart. This test measured the participant's ability to resolve very small differences in high contrast visual stimuli. It presented a range of stimuli from 20/25 to 20/4, with 20/20 being one minute of arc. A score of, for example, 20/16 should be interpreted to mean that this participant performs as well at 20 feet as the normal subject does at 16 feet. Smaller numbers mean better acuity.

The acuity chart was placed at eye level in a well-illuminated room. A modified Method of Limits psychophysical procedure was used to determine threshold acuity. Participants were asked to read each line of the chart aloud from the left margin, beginning with the top line (easiest, 20/25). Each line contained five Es, each one in either the up, down, left, or right orientation. Participants responded "up," "down," "left," or "right" to each successive E. Threshold was defined as the acuity value of the smallest line on which the participant got at least four of the five correct. When the participant missed two or more on a given line, the test was terminated and the threshold recorded.

Visual contrast sensitivity was measured binocularly from a distance of 10 feet (3.05 meters) using the Vistech Vision Contrast Test System chart (configuration B). This test measured the participant's ability to resolve very small differences in brightness contrast between adjacent spatial locations. The Vistech chart displayed sine-wave gratings (parallel lines) varying in spatial frequency and brightness contrast. Forty circular patches of sine-wave gratings were organized into five horizontal rows of eight patches each. Each of the rows was a different spatial frequency increasing from top to bottom (1.5, 3.0, 6.0, 12.0, and 18.0 cycles/degree). Within each row, brightness contrast decreased in regular decrements from the left-most patch (interval number one) to the right-most patch (interval number eight).

The contrast sensitivity chart was placed at eye level in a well-illuminated room. A modified Method of Limits psychophysical procedure was used to determine threshold contrast sensitivity. Participants were asked to read each row of the chart aloud from left to right. The lines of each grating patch were oriented either left, right, or straight up. Participants responded "left," "right," or "up" to each successive grating patch. Threshold was defined as the highest interval number (the lowest brightness contrast patch) that the participant correctly identified in a row. When the participant incorrectly identified a patch, the threshold for that row was recorded and the participant went on to the next lower row (higher spatial frequency). In this fashion a threshold was determined for all five rows (all five spatial frequencies).

The resting focal distance (also called dark focus distance or resting accomodation distance) was measured for the right eye using a polarized vernier optometer built by Illiana Aviation Sciences, Limited. This test measured the participant's resting accomodation distance in diopters plus a constant 10. A diopter is a unit of measurement of the refractive power of an optical lens—such as the lens of the human eye. Distance measured in diopters is proportional to the reciprocal of the focal distance in meters (e.g., 0 diopters equals a focal length of infinity, 1 diopter equals a focal length of 1 meter, 2 diopters equals a focal length of 0.50 meters, 3 diopters equals a focal length of 0.33 meters, etc.). Thus, large numbers represent short focal length and vice versa. Since the resting focal distance of many people is between infinity and one meter, a common convention is to add the constant 10 to the diopter value to make the numbers easier to work with.

Focal distance is the distance from the lens of the eye to the point focussed upon. This distance typically varies from about 15 centimeters to optical infinity (about 6.10 meters). Resting (or dark) focal distance refers to the focal length of the resting eye. That is, an eye that is not focussing upon anything—such as an eye that is in the dark. People vary in their resting focal distance.

Testing was performed in a dark room. Each participant placed his head on a chin rest and adjusted this chin rest until his right eye was optimally positioned to view the stimuli from a distance of about 15 centimeters. The stimuli were three lighted, vertical line segments which were flashed simultaneously for a duration of 500 milliseconds. The upper and lower line segments were aligned in fixed positions. The middle line segment could be adjusted to the right or left until it was precisely aligned with the other two. The participant's task was to align the three line segments by telling the experimenter after each trial (flash) that the middle segment was either "left," "right," or "centered" relative to the upper and lower segments. The middle line would be perceived as centered when it was presented at the participants resting focal point.

A Method of Limits psychophysical procedure was employed to determine resting focal distance. Six measurements were performed. Three measurements began with the middle segment well left (inward) and proceeded right (outward) until the participant responded "centered." Three measurements began with the middle segment far right (outward) and proceeded left (inward) until the participant responded "centered." Far left and far right starting points alternated. The resting focal distance for each participant was defined as the mean of these six measurements.

<u>Field testing</u>. The 16S personnel were tested in the RTS during their last week of AIT. Due to requirements for classroom time, field data collection took place on Saturday, Sunday, and Monday. Weapons were set-up and calibrated on Friday.

Personnel were brought to the RTS site by an instructor who in no way interfered with the test or coached the participants during the test. Upon arrival, the trainees were briefed in detail as to the nature of the research as appropriate and what was specifically required of them (e.g., allocation of team chief tasks, allocation of gunner tasks). Trainees were shown examples of stress and workload questionnaires and instructed in how and when to complete them. Personnel arrived at the RTS site as members of preexisting teams in which they received their Advanced Individual Training. These preexisting teams were randomly assigned to weapon positions. Each team chose their own individual duty assignments (i.e., team chief or gunner).

[NOTE: Typically, a new AIT graduate would not be a team chief. For purposes of this experiment, however, leader-gunner teams were a requirement. So trainees were chosen as "acting" team leaders. This did not prove to be a problem, procedurally, since the trainees were knowledgeable and eager to perform as team chiefs.]

Once at a weapon position, the data collector reviewed the engagement actions with the team and showed them their sector of responsibility, left limit, right limit, and primary target line (PTL). Each team was responsible for defending the same 90 degree search sector. Procedures were employed to keep all weapon positions visually and aurally independent of one another so that no cross cuing occurred.

Each team received 13 data trials under conditions of MOPP0 and 13 under MOPP4. MOPP0 and MOPP4 trials occurred in a group either during the morning or during the afternoon. The schedule of MOPP0 and MOPP4 trials was counterbalanced across days of the experiment as presented in Table 3. Prior to each morning and afternoon session a practice trial was run which contained both a fixed-wing and a rotary-wing aircraft. Participants received feedback on their performance at the end of the day after they finished both the MOPP0 and the MOPP4 sessions.

The same 13 scenarios were presented to all teams both in the MOPP0 and the MOPP4 sessions—but in a different counterbalanced order. The counterbalanced ordering of scenario presentations varied both across sessions within a day and across test days. The counterbalancing scheme was constrained by the practical necessity not to have two fixed-wing trials back-to-back (i.e., to save preparation time). The 13 test scenarios are described in Table 4. These 13 scenarios presented the participating teams with a variety of aircraft targets. Scenarios varied in aircraft type, intent, model, number of aircraft per scenario, range, aspect angle, aircraft ingress azimuth, duration of availability, and level of difficulty.

All data were collected under conditions of Weapons Control Status Tight. This meant that soldiers were required to make their tactical identification based upon visual criteria (e.g., Soviet aircraft were hostile, US aircraft were friendly).

Each trial began when the data collector gave the team a verbal alerting message. This message stated that air activity was imminent and reminded the team of their Weapons Control Status (i.e., "Red! Tight!"). The data collector verbally signalled the end of a trial by alerting the team that the current air attack had subsided ("Return to condition yellow."). Each team was instructed in the discrete trial procedure employed, and reminded of the trial-begin and trial-end signals.

Soldiers completed stress and workload questionnaires as part of field testing. The stress questionnaire (Self-Evaluation Questionnaire, Spielberger, 1983) was administered twice during each session—once just prior to beginning and again just after finishing each session. The workload questionnaire (TLX Rating Scales, NASA-Ames, 1986) was administered immediately after each data trial during both MOPP0 and MOPP4 sessions.

Table 4

Test Scenario Specifications

Scen. No.	No. Targ.	Type	Intent	A.C. Model	Cl. Az.	Degrees Aspect	KM Range	Pres. Order	Sec. Avail.	Level of Diff.
01	1	FW	F	A10	11	45	**	—	—	Medium
02	1	FW	F	A7	1	45	**	—	—	Medium
03	1	FW	H	Su25	11	45	**	—	—	Medium
04	1	FW	H	Su20/22	1	45	**	—	—	Medium
05	2	Mix	H	Su25	12	0	**	Simul	—	High
		Mix	H	Mi24	12	90	3.5*	Simul	50	High
06	1	RW	F	UH1	11	270	3.5*	—	50	Low
07	1	RW	F	AH1	12	315	3.5*	—	50	Low
08	1	RW	F	AH64	1	90	3.5*	—	50	Low
09	1	RW	H	Mi28	11	315	3.5*	—	50	Low
10	1	RW	H	Mi24	12	90	3.5*	—	50	Low
11	1	RW	H	Mi8	1	45	3.5*	—	50	Low
12	3	RW	F	UH1	11	270	3.5*	Simul	100	High
		RW	F	AH1	12	315	3.5*	Simul	100	High
		RW	F	AH64	1	90	3.5*	Simul	100	High
13	3	RW	H	Mi28	11	315	3.5*	Simul	100	High
		RW	H	Mi24	12	90	3.5*	Simul	100	High
		RW	H	Mi8	1	45	3.5*	Simul	100	High

** Target becomes available for engagement at a range of at least 16 kilometers. Target is within team's search sector but outside visual detection range. Target flies an ingressing pattern until reaching one kilometer from team, then turns and flies back to base.

* Target rises from stationary, defilade position to become available for engagement, hovers for predetermined number of seconds, then returns to defilade position.

Stinger Baseline (Sub-Experiment 1) was without cuing information. Each team was responsible for searching the full 90 degree sector to detect available targets. In Stinger Cuing (Sub-Experiment 2) all targets in all scenarios were visually cued as to number (how many), type (FW or RW), clock azimuth (11, 12, or 1, where 12 was PTL), and range (in full-scale kilometers). Targets were not cued as to identity. Examples of the cuing displays are presented in Appendix A for all 13 scenarios. These visual cues were presented for each scenario on a trial-by-trial basis coincident with the verbal alert. The team chief examined this display, cued the gunner, and both began searching.

The cuing displays were designed to be consistent with the screen format employed in the Enhanced Hand-Held Terminal Unit (EHTU) currently being developed for the Forward Area Air Defense Command-Control Intelligence (FAAD C2I) system (TRW, 1990). The EHTU when fielded in (approximately) 1995 is expected to provide precise, accurate cuing information for FAAD fire units. The size, format, and symbology used in the 13 cuing displays were designed to describe each of the 13 scenarios in terms consistent with the 1990 version of the EHTU. The cues depicted the Stinger team as the box symbol in the center of the screen display. Targets were the "U" symbols. The "U" stands for "unknown" because the experimental conditions forced the team to identify each aircraft visually as per Weapons Control Status Tight. The "U" symbols with bars above them represent RW aircraft. Those without bars represent FW aircraft. The straight lines emerging from the center of each "U" represent aircraft heading and speed. Long lines represent fast movers and short lines represent slow movers. All teams were instructed in the use of the cues and were given practice with feedback before data trials were run. All teams found the graphic displays easy to understand and use.

The procedure followed during a baseline data trial was this: data collector shouts alert red; team members stand up and take their positions—gunner shoulders Stinger while chief searches sector for aircraft; upon detection of aircraft, team performs standard tactical engagement sequence including team chief using binoculars to identify aircraft—if a multiple target scenario, the engagement sequence is repeated anew for each target; team searches sector for aircraft until data collector shouts reduced alert status yellow; gunner then returns Stinger to rack; team members return to seats at weapon position—sitting with their backs to the range between trials; and finally, team chief and gunner complete workload questionnaire for the trial just completed. The procedure followed during a cuing data trial was identical except, as noted above, visual cues were presented at the time of the verbal alert.

The design of this experiment was a mixed factorial with two levels of the MOPP factor (0 and 4) and two levels of the cuing factor (no cues and cues). The MOPP factor was a within subjects manipulation—with all participants receiving both the MOPP0 and the MOPP4 conditions. The cuing factor was a between subjects manipulation—with all participants in Sub-Experiment 1 (Baseline) receiving the no cues condition and all participants in Sub-Experiment 2 (Cuing) receiving the cues condition.

Hypotheses

Air defense engagement tasks were expected to be performed less well under conditions of MOPP4, when compared to the MOPP0 conditions. These same engagement tasks were expected to be performed better when cuing information was provided than when no cues were present. The addition of the cuing information was hypothesized to reduce at least some of the degradation in performance lost to MOPP4 in the uncued, baseline condition.

Participants were expected to report greater stress during the MOPP4 conditions, when compared to the MOPP0 conditions. Participants were also expected to report greater workload during conditions of wearing MOPP4. The measures of visual sensitivity were expected to correlate systematically with measures of the team chief's detection and identification performance.

Results

Engagement Performance

Data for fixed-wing Task Performance Measures (e.g., detection range, identification range, etc.) were aggregated across FW scenarios (Scenarios 1, 2, 3, 4, and the FW portion of 5) for each condition for each team. Data for rotary-wing Task Performance Measures (e.g., time from target available to detect, time from detect to IFF, etc.) were aggregated across RW scenarios (Scenarios 6, 7, 8, 9, 10, 11, and the first RW detected in Scenarios 12 and 13) for each condition for each team. Scores for each Task Performance Measure were aggregated across similar scenarios (either FW or RW) by taking the arithmetic mean of the engagement measures recorded in RTS.

Summary Performance Measures (e.g., percent aircraft detected, percent aircraft correctly identified, etc.) were calculated over relevant scenarios for each condition for each team. For example, FW percent aircraft detected was calculated over Scenarios 1, 2, 3, 4, and the FW portion of 5. RW percent aircraft detected was calculated over Scenarios 6, 7, 8, 9, 10, 11, 12, and 13. For another example, FW percent friendly fratricide was calculated over Scenarios 1 and 2. RW percent friendly fratricide was calculated over Scenarios 6, 7, 8, and 12. For SPMs (but not TPMs) all three RW targets in Scenarios 12 and 13 were included.

Engagement performance was analyzed by a mixed two factor Analysis of Variance (ANOVA). The within subjects factor was MOPP level. The between subjects factor was presence or absence of cues. One such mixed ANOVA was performed for each of the measures of engagement performance using the SPSS/PC+ Advanced Statistics software package (Norusis, 1986, pps. B153-B181). The effect of cuing was tested against between-subjects variability, while both the MOPP effect and the cuing by MOPP interaction effect were tested against within-subjects variability. Due to the relatively small samples collected plus the notoriously large variability common to applied field research, alpha probabilities as high as ten percent will be reported for the engagement performance results.

Data presented in tables are the arithmetic mean (Mean), the standard deviation (SD), and the number (N) of data points (i.e., the number of teams) upon which these descriptive statistics are based. It will be noted that the number of data points for FW targets is smaller than the number for RW targets. This is because technical difficulties with the PLS prevented some teams from being given the FW scenarios. No make-ups were possible due to the tight schedule of testing.

Results for fixed-wing aircraft: TPMs. Task Performance Measures are presented in Tables 5 through 11 by dependent variable. Generally, the greater the incoming ranges the better the performance. Positive ranges are incoming; negative ranges are outgoing. Table 5 presents detection range as a function of MOPP level and presence or absence of cues. Aircraft were detected at significantly greater range under conditions of MOPP0 (7.59 kilometers) than under conditions of MOPP4 (6.74 kilometers) [$F(1, 20) = 3.18$, $p<.10$]. Aircraft were also detected at significantly greater range during the cue condition (7.76 kilometers) than during the no cue condition (6.57 kilometers) [$F(1, 20) = 9.99$, $p<.01$]. There was no interaction between MOPP level and presence or absence of cues [$F(1, 20) = 0.62$, $p>.10$].

Table 5

Detection Range in Kilometers for Fixed-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	6.80	6.33	8.37	7.15
SD	0.81	0.84	1.71	1.45
N	8	8	14	14

Note. Positive ranges are incoming.

Table 6 presents the range at IFF as a function of MOPP level and cue condition. Aircraft were interrogated at significantly greater range under conditions of MOPP0 (6.83 kilometers) than under conditions of MOPP4 (5.66 kilometers) [$F(1, 20) = 2.96$, $p<.10$]. Aircraft were also interrogated at significantly greater range during the cue condition (7.42 kilometers) than during the no cue condition (5.07 kilometers) [$F(1, 20) = 7.03$, $p<.05$]. Again, there was no interaction between MOPP level and presence or absence of cues [$F(1, 20) = 0.01$, $p>.10$].

Table 6

IFF Range in Kilometers for Fixed-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	5.61	4.53	8.05	6.79
SD	4.43	2.51	1.46	2.00
N	8	8	14	14

Note. Positive ranges are incoming.

Table 7 presents weapon acquisition range for the aircraft as a function of MOPP level and cue condition. There was no statistically significant effect of MOPP level upon acquisition range [$F(1, 20) = 0.50$, $p > .10$]. Acquisition range was significantly greater during the cue condition (4.53 kilometers) than during the no cue condition (1.55 kilometers) [$F(1, 20) = 8.36$, $p < .01$]. There was no interaction between MOPP level and cue condition [$F(1, 20) = 0.21$, $p > .10$].

Table 7

Acquisition Range in Kilometers for Fixed-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	2.04	1.07	4.63	4.42
SD	3.26	2.88	3.58	2.12
N	8	8	14	14

Note. Positive ranges are incoming.

Table 8 presents identification range as a function of MOPP level and cue condition. Aircraft were identified at significantly greater range under conditions of MOPP0 (2.61 kilometers) than under conditions of MOPP4 (0.45 kilometers) [$F(1, 20) = 10.22$, $p < .01$]. Aircraft were also identified at significantly greater range during the cue condition (2.45 kilometers) than during the no cue condition (0.61 kilometers) [$F(1, 20) = 8.02$, $p < .01$]. Again, there was no interaction between MOPP level and cue condition [$F(1, 20) = 0.51$, $p > .10$].

Table 8

Identification Range in Kilometers for Fixed-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	1.45	- 0.22	3.77	1.13
SD	2.33	2.00	2.01	2.15
N	8	8	14	14

Note. Positive ranges are incoming; negative ranges are outgoing.

Table 9 presents the range at weapon lock-on as a function of MOPP level and presence or absence of cues. There was no effect of MOPP level on lock-on range [$F(1,20) = 0.04$, $p > .10$]. Lock-on was, however, performed at a significantly greater range in the cue condition (1.53 kilometers) than in the no cue condition (- 0.97 kilometers) [$F(1, 20) = 8.43$, $p < .01$]. There was no interaction between MOPP and cuing [$F(1, 20) = 0.22$, $p > .10$].

Table 9

Lock-On Range in Kilometers for Fixed-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	- 1.07	- 0.86	1.77	1.29
SD	3.04	2.15	2.81	2.19
N	8	8	14	14

Note. Positive ranges are incoming; negative ranges are outgoing.

Table 10 presents the range at fire as a function of MOPP conditions and cue conditions. There was no statistically significant effect of MOPP upon fire range [$F(1, 20) = 0.55$, $p > .10$]. Fire was performed at a significantly greater range during the cue condition (0.55 kilometers) than during the no cue condition (- 1.85 kilometers) [$F(1, 20) = 8.69$, $p < .01$]. Again, there was no interaction between MOPP level and cue condition [$F(1, 20) = 0.34$, $p > .10$].

Table 10

Fire Range in Kilometers for Fixed-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	- 1.79	- 1.91	1.06	0.04
SD	3.31	2.00	2.89	1.83
N	8	8	14	14

Note. Positive ranges are incoming; negative ranges are outgoing.

Table 11 presents the percentage of the total possible tracking time interval that the gunner was actually tracking the target by conditions of the experiment. There was no statistically significant effect of either MOPP level [$F(1, 20) = 0.60$, $p>.10$] or cuing [$F(1, 20) = 0.22$, $p>.10$]. There was no interaction between MOPP and cuing [$F(1, 20) = 0.37$, $p>.10$].

Table 11

Percent of Total Tracking Time on Target for Fixed-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	75.25	77.00	73.21	88.07
SD	34.21	37.10	33.50	27.53
N	8	8	14	14

The effects of MOPP level and cuing upon Task Performance Measures can be seen clearly when presented graphically. Figures 1 through 4 display the FW aircraft ranges for selected engagement events. Figure 1 displays the results for all conditions of the experiment. Figures 2 through 4 display critical subsets of these results, and thereby highlight key effects implicit in the analyses described above.

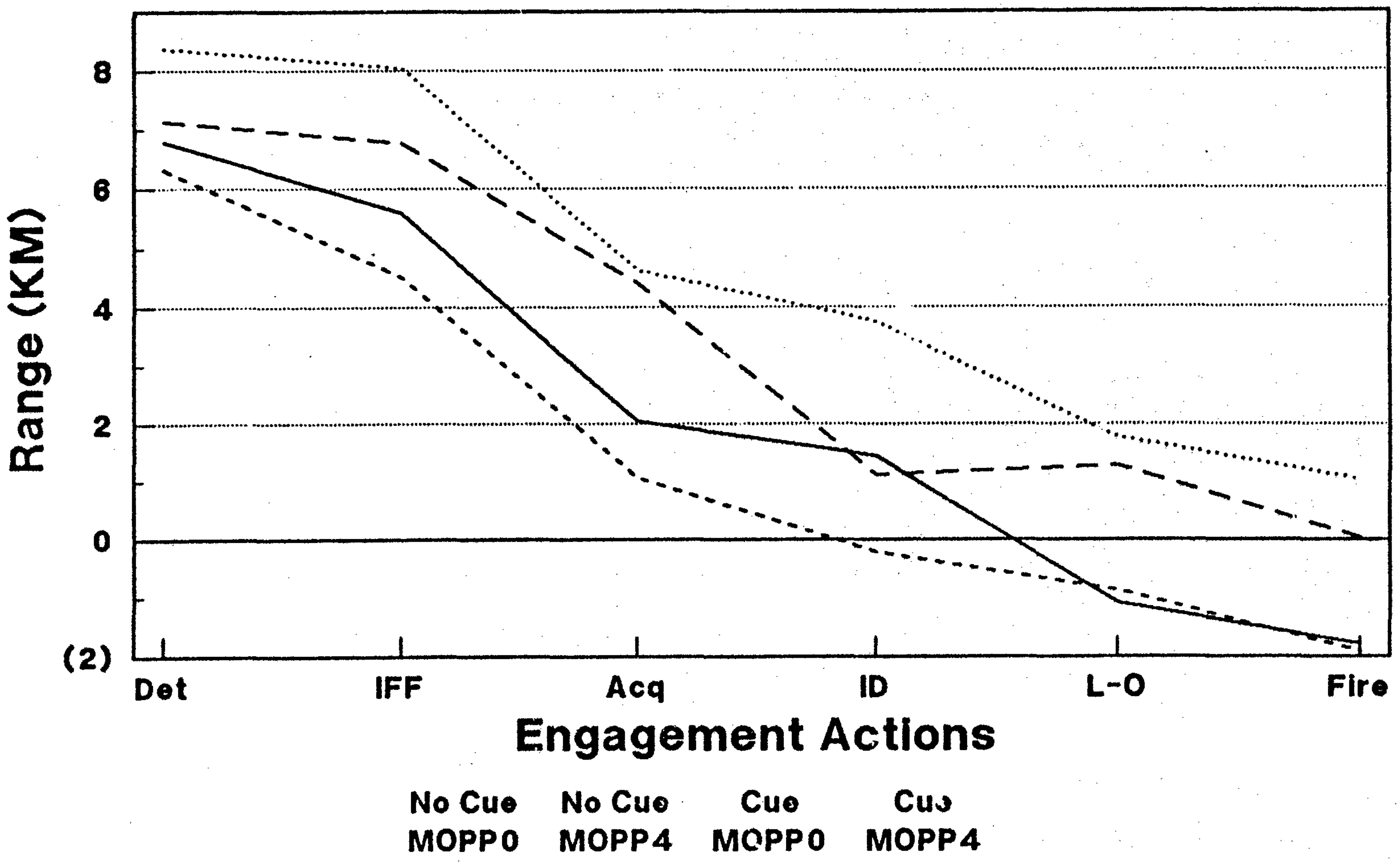

Figure 1. Range of engagement actions for fixed-wing targets: All conditions

Figure 2 shows the results of the MOPP0 versus MOPP4 comparison summed over the no cue condition (Sub-Experiment 1) and the cue condition (Sub-Experiment 2). Over all six engagement actions (detection through fire), the mean difference in performance was 0.91 kilometers favoring MOPP0. The largest difference was for identification where MOPP0 was superior by 2.16 kilometers.

Figure 3 shows the results of the comparison between the no cue condition and the cue condition summed over MOPP0 and MOPP4. Over all six engagement actions, the cue condition was superior by a mean range of 2.21 kilometers.

Figure 4 presents a comparison between the no cue condition of MOPP0 and the cue condition of MOPP4. The MOPP4 condition in this comparison was superior to the MOPP0 condition in five of the six engagement actions by a mean range of 1.62 kilometers. Figure 4 is useful because it quantifies the extent to which adding cues alleviated the degradation due to MOPP4 for these soldiers in these FW scenarios.

Results for fixed-wing aircraft: SPMs. Fixed-wing Summary Performance Measures and associated analyses will only be presented in detail where there were statistically significant results. The mean overall percentage of aircraft detected was 99.37. The mean overall percentage of aircraft correctly identified (hostile plus friendly) was 56.49. The mean overall percentage of hostile aircraft correctly identified was 63.59.

Table 12 shows percent friendly aircraft correctly identified as a function of MOPP level and presence or absence of cues. The correct identification rate was significantly higher under the MOPP0 condition (58.48%) than under MOPP4 (39.73%) [$F(1, 20) = 3.37$, $p < .10$]. There was no effect of cues [$F(1, 20) = 0.02$, $p > .10$], and no interaction between MOPP level and condition of cuing [$F(1, 20) = 0.37$, $p > .10$].

Table 12

Fixed-Wing: Percent Friendly Aircraft Correctly Identified by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	56.25	43.75	60.71	35.71
SD	17.68	17.68	34.96	45.69
N	8	8	14	14

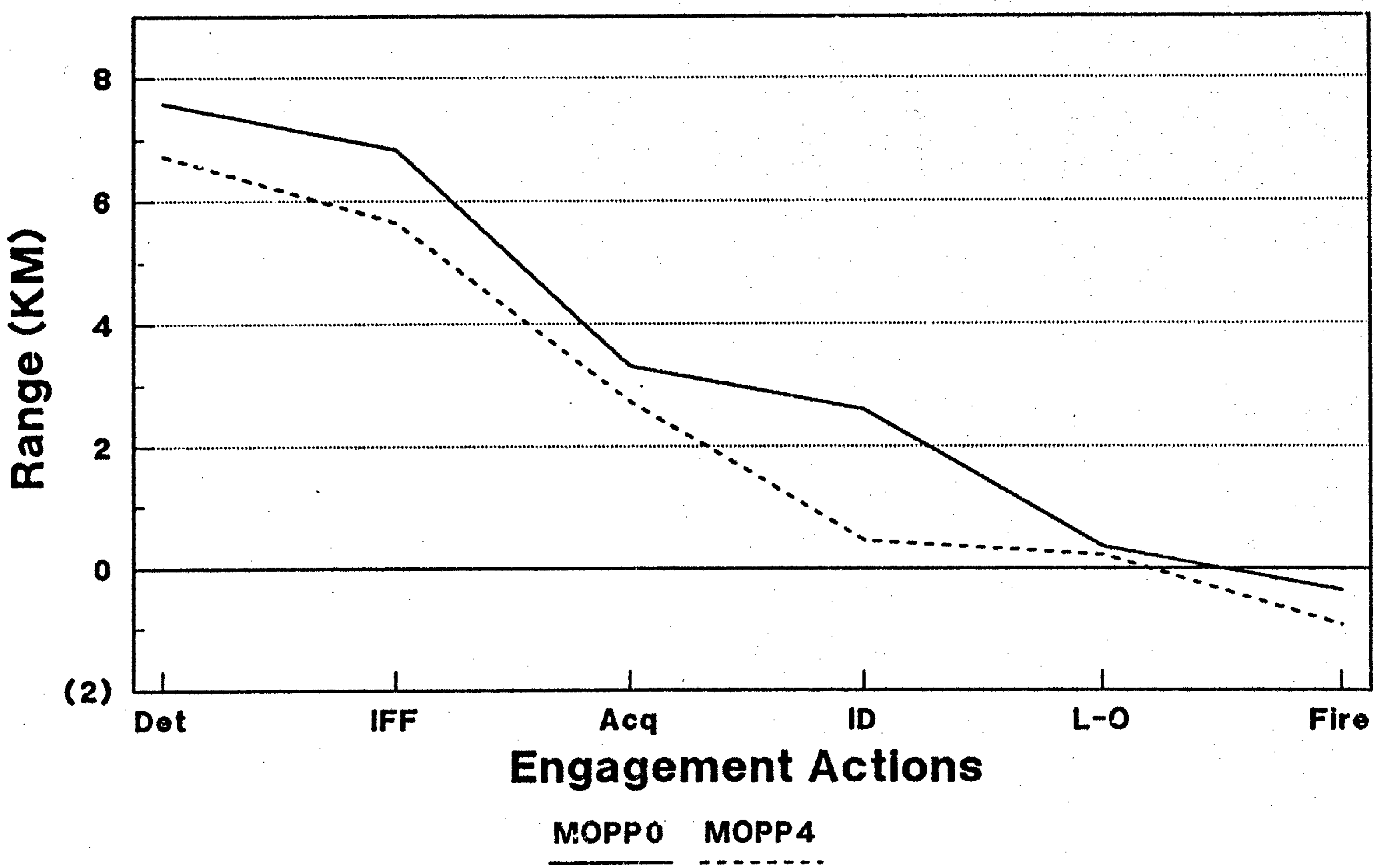

Figure 2. Range of engagement actions for fixed-wing targets: MOPP0 versus MOPP4 (summed over both conditions of cuing).

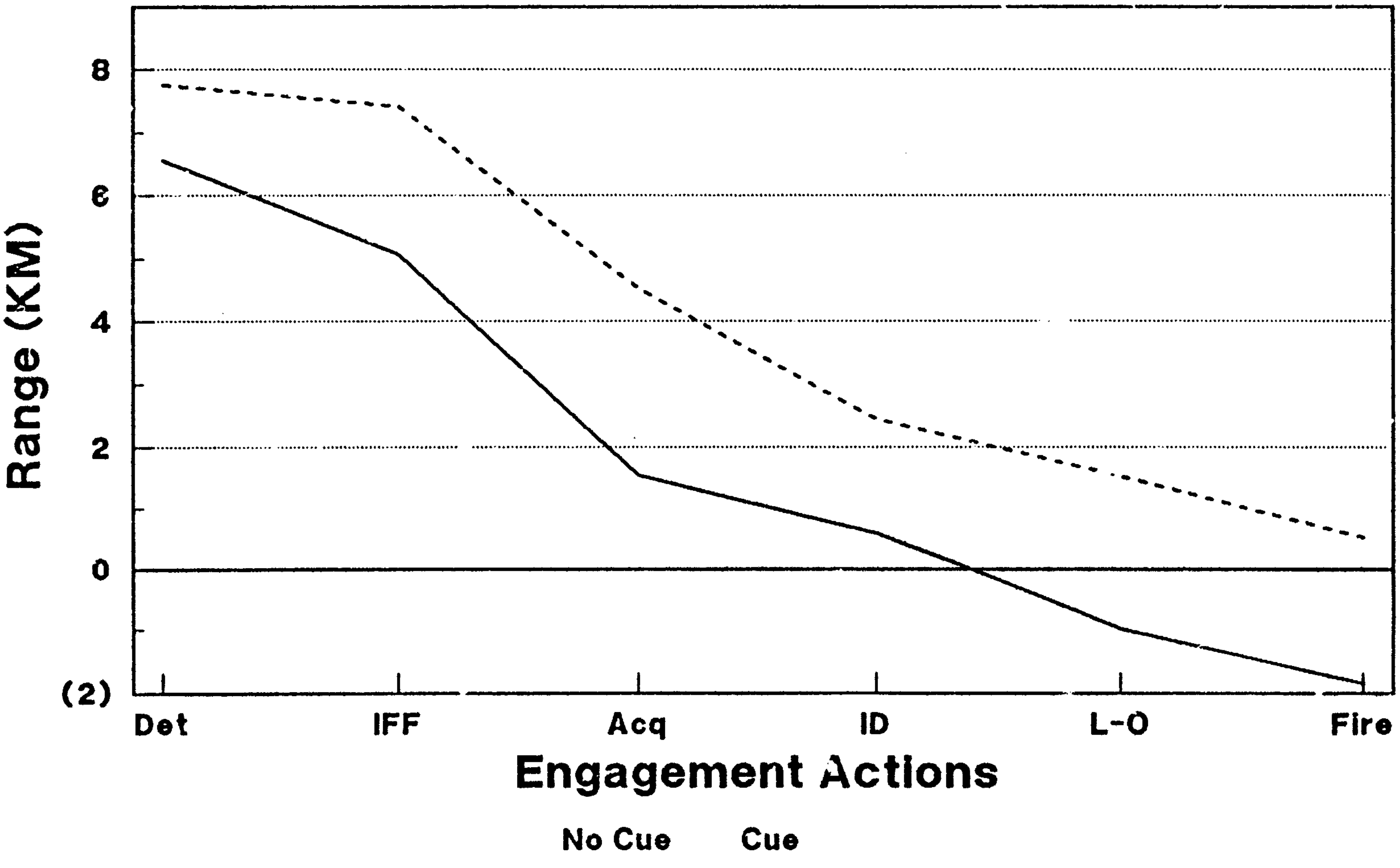

Figure 3. Range of engagement actions for fixed-wing targets: No cue versus cue (summed over both conditions of MOPP).

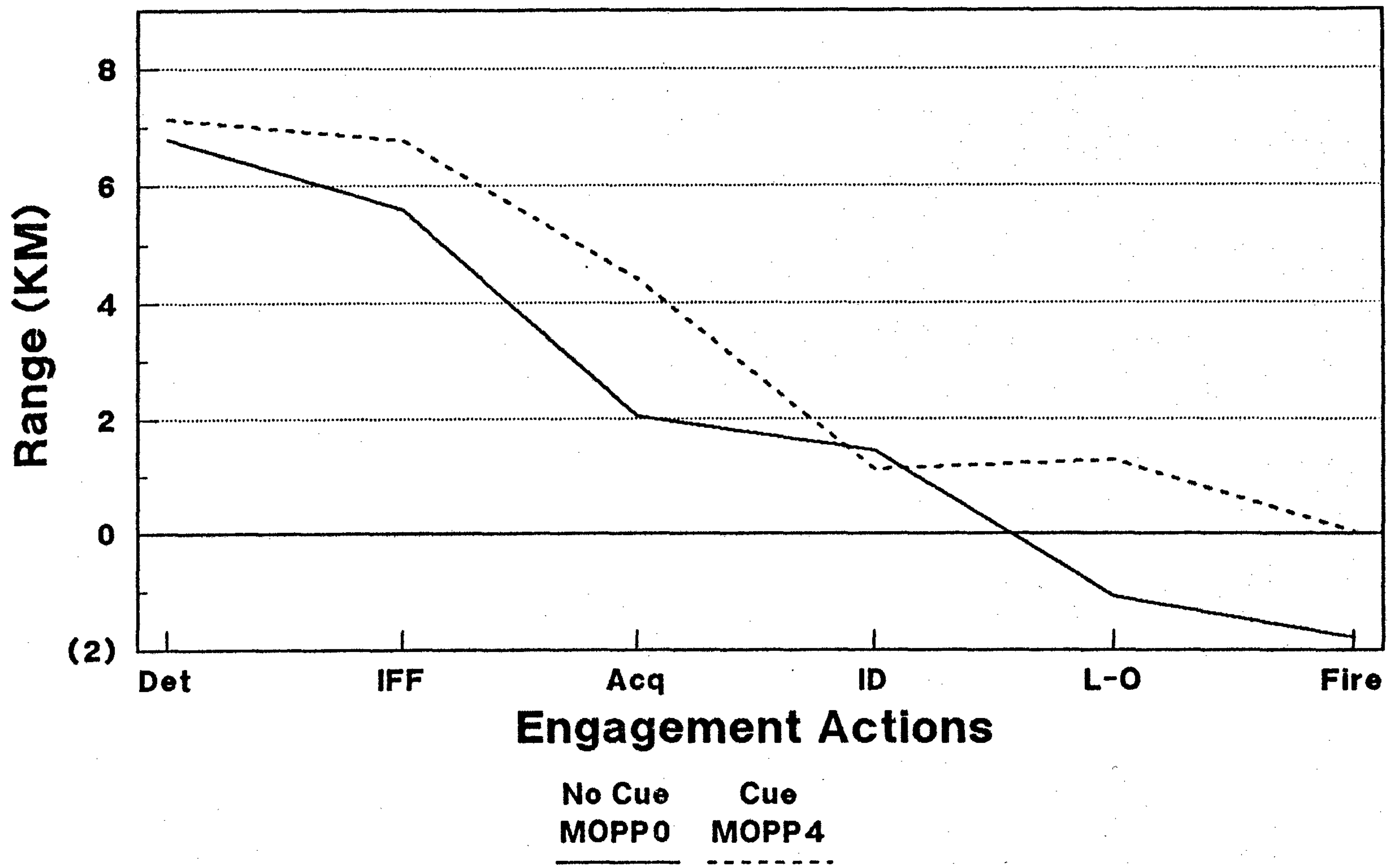

Figure 4. Range of engagement actions for fixed-wing targets: No cue MOPP0 versus cue MOPP4.

Table 13 displays hostile aircraft attrition aggregated over MOPP conditions and cue conditions. There was no statistically significant difference in attrition between MOPP0 and MOPP4 [$F(1, 20) = 0.20$, $p > .10$]. Attrition was, however, significantly greater when cues were presented (57.14%) than when no cues were presented (32.31%) [$F(1, 20) = 3.13$, $p < .10$]. There was no interaction between MOPP and cuing [$F(1, 20) = 0.20$, $p > .10$].

Table 13

Fixed-Wing: Percent Hostile Aircraft Attrition by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	27.13	37.50	57.14	57.14
SD	30.89	37.62	44.24	43.73
N	8	8	14	14

The mean overall fratricide rate was 26.79 percent. The mean overall percentage of hostile aircraft credited as destroyed ("killed") prior to ordnance release was 13.90. (The ordnance release point for hostile FW aircraft was defined as two kilometers from the weapon position. Killing an aircraft prior to ordnance release was defined as firing early enough in the engagement sequence to allow the missile time to intercept the flight path of the aircraft prior to the incoming aircraft reaching the two kilometer point.) The mean overall conditional probability of a kill given fire was 58.01 percent.

Results for rotary-wing aircraft: TPMs. Task Performance Measures are presented in Tables 14 through 21 by dependent variable. Generally, the shorter the engagement times the better the performance. Table 14 presents the time from target available to detect as a function of MOPP level and presence or absence of cues. There were no statistically significant differences in detection times for MOPP level [$F(1, 25) = 2.58$, $p = .12$] or cues [$F(1, 25) = 0.03$, $p > .10$], and no interaction between the two [$F(1, 25) = 2.16$, $p > .10$].

Table 14

Time from Target Available to Detection in Seconds for Rotary-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	7.00	8.50	7.59	7.65
SD	0.82	2.37	2.40	2.55
N	10	10	17	17

Table 15 shows the time from detection to identification (ID) as a function of conditions of MOPP and cuing. Times from detect to ID were significantly longer in the MOPP4 condition (10.92 seconds) than in the MOPP0 condition (9.27 seconds) [$F(1, 25) = 4.92$, $p<.05$]. There were no statistically significant differences as a function of cuing [$F(1, 25) = 0.05$, $p>.10$], nor was there a MOPP by cuing interaction [$F(1, 25) = 0.11$, $p>.10$].

Table 15

Time from Detection to Identification in Seconds for Rotary-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	9.00	10.90	9.53	10.94
SD	2.31	4.75	3.08	4.60
N	10	10	17	17

Table 16 displays the time from target detection to IFF interrogation by conditions of the experiment. There were no statistically significant differences in IFF times for conditions of MOPP [$F(1, 24) = 1.97$, $p>.10$]. IFF times were, however, significantly shorter during the cue condition (2.65 seconds) than during the no cue condition (4.45 seconds) [$F(1, 24) = 6.01$, $p<.05$]. There was no MOPP by cuing interaction [$F(1, 24) = 0.21$, $p>.10$].

Table 16

Time from Detection to IFF in Seconds for Rotary-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	3.90	5.00	2.37	2.94
SD	2.77	3.53	1.15	2.02
N	10	10	16	16

Table 17 presents the time from detection to weapon acquisition as a function of MOPP level and condition of cuing. There was a statistically significant interaction between MOPP and cuing [$F(1, 24) = 5.84$, $p<.05$]. Acquisition time was substantially longer for MOPP4 in the no cue condition (accounting for the significant main effect of MOPP, [$F(1, 24) = 5.26$, $p<.05$], while in the cue condition there was essentially no difference between MOPP0 and MOPP4. Acquisition times were shorter in the cue condition (7.31 seconds) than in the no cue condition (10.80 seconds) [$F(1, 24) = 4.09$, $p<.05$].

Table 17

Time from Detection to Weapon Acquisition in Seconds for Rotary-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	8.40	13.20	7.37	7.25
SD	3.78	7.48	4.06	4.51
N	10	10	16	16

Table 18 shows the time from weapon acquisition to lock-on by conditions of the experiment. Lock-on times were significantly longer while wearing MOPP4 (5.33 seconds) than while in MOPP0 (3.77 seconds) [$F(1, 24) = 3.09$, $p<.10$]. There were no statistically significant differences as a function of cuing [$F(1, 24) = 0.47$, $p>.10$]. Also, there was no MOPP by cuing interaction [$F(1, 24) = 2.35$, $p>.10$].

Table 18

Time from Weapon Acquisition to Lock-On in Seconds for Rotary-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	3.90	4.10	3.63	6.56
SD	4.31	4.61	3.34	5.55
N	10	10	16	16

Table 19 displays the time from lock-on to fire as a function of MOPP level and presence or absence of cues. Times were significantly longer for the MOPP4 condition (3.83 seconds) than during the MOPP0 condition (2.75 seconds) [$F(1, 24) = 19.29$, $p<.001$]. Times were significantly shorter for the cue condition (2.69 seconds) than for the no cue condition (3.90 seconds) [$F(1, 24) = 5.52$, $p<.05$]. There was no interaction between MOPP level and cuing [$F(1, 24) = 1.76$, $p>.10$].

Table 19

Time from Lock-On to Fire in Seconds for Rotary-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	3.20	4.60	2.31	3.06
SD	1.40	2.17	0.87	1.29
N	10	10	16	16

Table 20 presents the time from identification to fire as a function of MOPP level and presence or absence of cues. Times were significantly longer for the MOPP4 condition (9.07 seconds) than for the MOPP0 condition (5.89 seconds) [$F(1, 24) = 5.26$, $p<.05$]. There were no statistically significant differences in times as a function of cuing [$F(1, 24) = 1.81$, $p>.10$]. Neither was there an interaction between MOPP level and presence or absence of cues [$F(1, 24) = 0.65$, $p>.10$].

Table 20

Time from Identification to Fire in Seconds for Rotary-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	6.40	10.70	5.37	7.44
SD	3.50	7.33	2.47	6.50
N	10	10	16	16

Table 21 presents the cumulative time of the engagement from detection to fire by conditions of the experiment. Times were significantly longer in the MOPP4 condition (19.11 seconds) than in the MOPP0 condition (14.03 seconds) [$F(1, 24) = 9.52$, $p<.01$]. There were no statistically significant differences in times as a function of cuing [$F(1, 24) = 1.56$, $p>.10$]. Also, there was no MOPP level by condition of cuing interaction [$F(1, 24) = 0.15$, $p>.10$].

Table 21

Time from Detection to Fire in Seconds for Rotary-Wing Aircraft by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	15.20	20.90	12.87	17.31
SD	3.97	10.74	3.44	8.55
N	10	10	16	16

Summarizing the results presented in Tables 14 through 21 it can be seen that engagement actions required more time to be performed in MOPP4. Of the 16 MOPP0 versus MOPP4 comparisons displayed in the tables (8 TPMs x 2 conditions = 16), 15 (94%) resulted in longer MOPP4 times. Of the eight statistical tests of the MOPP-level differences in performance (one test each for eight TPMs), six (75%) met the criterion for statistical significance—and one, availability to detection, approached the criterion.

These differences can be seen clearly when the results are presented graphically. Figure 5 displays the MOPP0 versus MOPP4 comparisons for all eight TPMs summed over both Sub-Experiment 1 (no cue) and Sub-Experiment 2 (cue).

Summarizing over Tables 14 through 21 there were 16 cue versus no cue comparisons (8 TPMs x 2 conditions = 16). Twelve (75%) of these comparisons resulted in shorter times for the cue condition. Of the eight statistical tests of the cue versus no cue differences in performance (one test each for eight TPMs), three (37.5%) met the criterion for statistical significance. Clearly, the effect of cues served to reduce some engagement times. The cuing effect, however, was not so pronounced as that of MOPP. These results are presented graphically in Figure 6.

The reduction in the baseline decrement produced by the cue condition is displayed graphically in Figure 7. This figure presents all eight engagement action times for the no cue MOPP0 condition, the no cue MOPP4 condition, and, for comparison, the cue MOPP4 condition. Note that the cued condition of MOPP4 required less time than the uncued condition of MOPP4 for six of the eight engagement actions. Over the engagement sequence from detection to fire, the cued condition of MOPP4 was shorter than the uncued condition of MOPP4 by 3.59 seconds—a reduction of the baseline decrement by 63 percent [from Table 21: No Cue MOPP4 - No Cue MOPP0 = 5.70 (baseline decrement); Cue MOPP4 - No Cue MOPP0 = 2.11; 5.70 - 2.11 = 3.59 (reduction in baseline decrement); 3.59 / 5.70 = 0.63 (proportion of baseline decrement reduced)]. Figure 7 is useful because it quantifies the extent to which adding cues alleviated the degradation due to MOPP4 for these soldiers in these RW scenarios.

Perhaps a clearer method for presenting the rotary-wing engagement times is to examine the entire engagement sequence in terms of four critical periods (c.f., Johnson, Barber, & Lockhart, 1988): Target available to detect, detect to identify, identify to fire, and the total time from target available to fire. The mean times for these periods are presented in Table 22.

Table 22

Rotary-Wing: Mean Time in Seconds for Critical Engagement Periods by Conditions

Period	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Av. to Detect	7.00	8.50	7.59	7.65
Detect to ID	9.00	10.90	9.53	10.94
ID to Fire	6.40	10.70	5.37	7.44
Av. to Fire	22.40	30.10	22.49	26.03

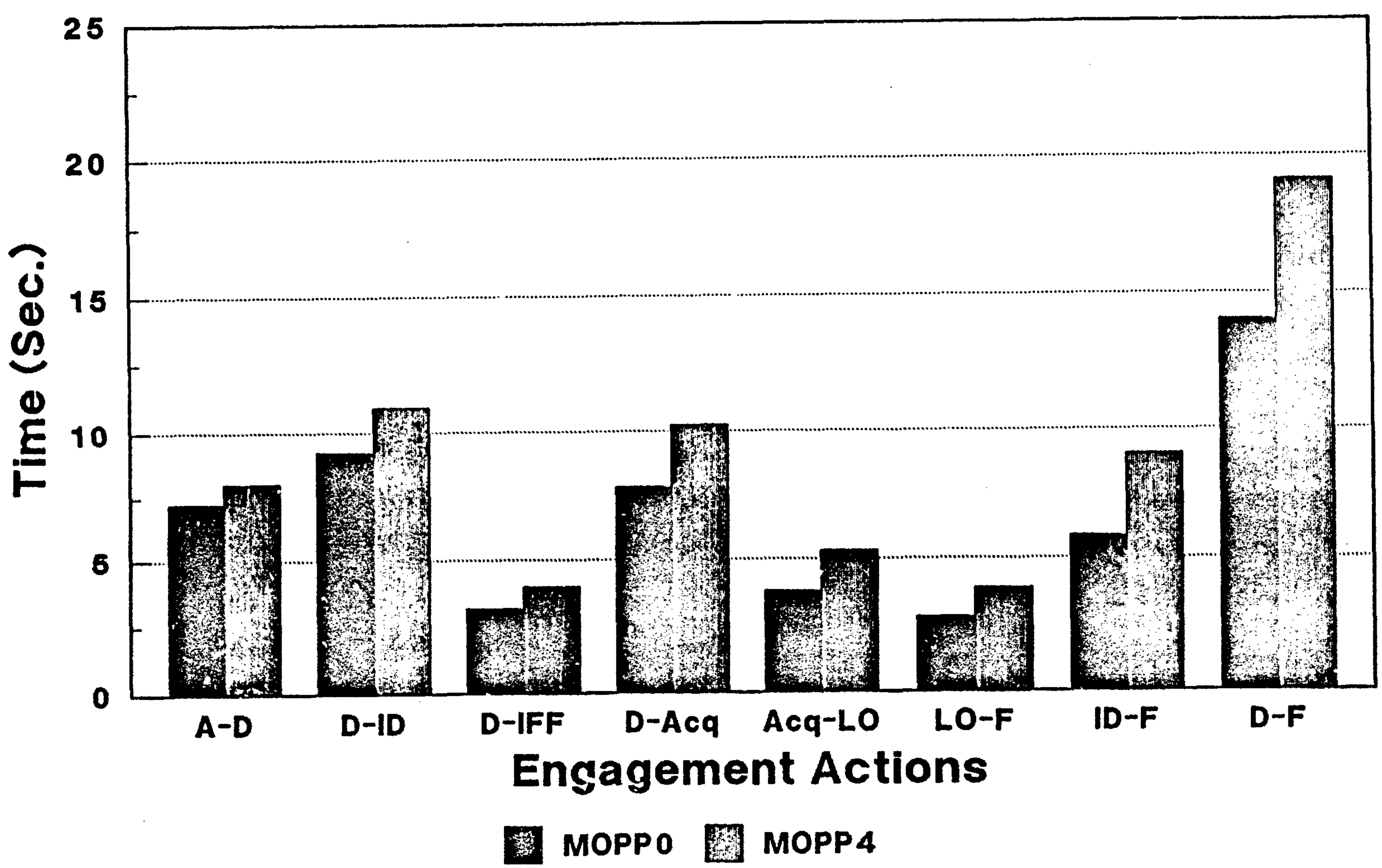

Figure 5. Time to perform engagement actions for rotary-wing targets: MOPP0 versus MOPP4 (summed over both cue conditions).

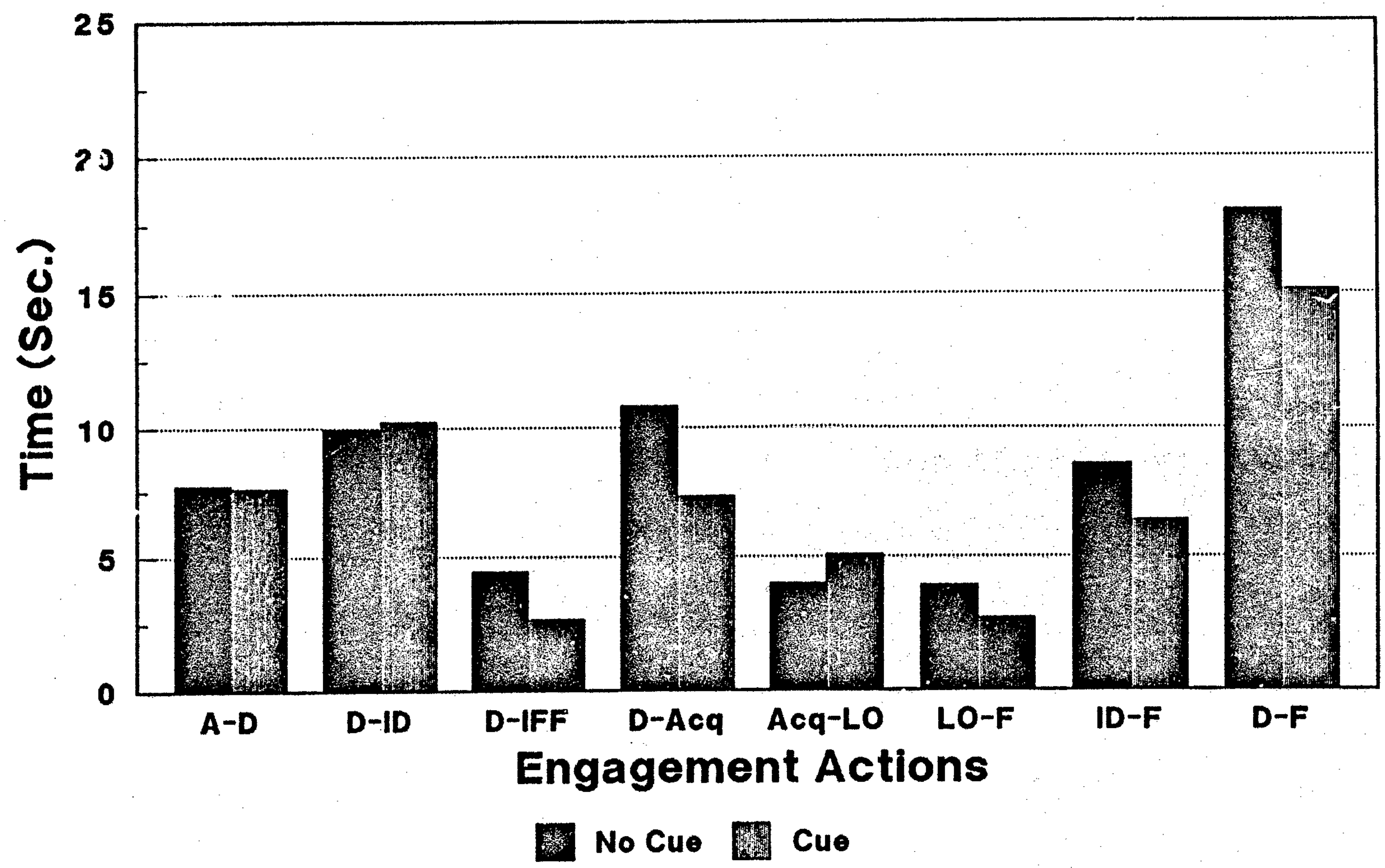

Figure 6. Time to perform engagement actions for rotary-wing targets: No cue versus cue (summed over both MOPP conditions).

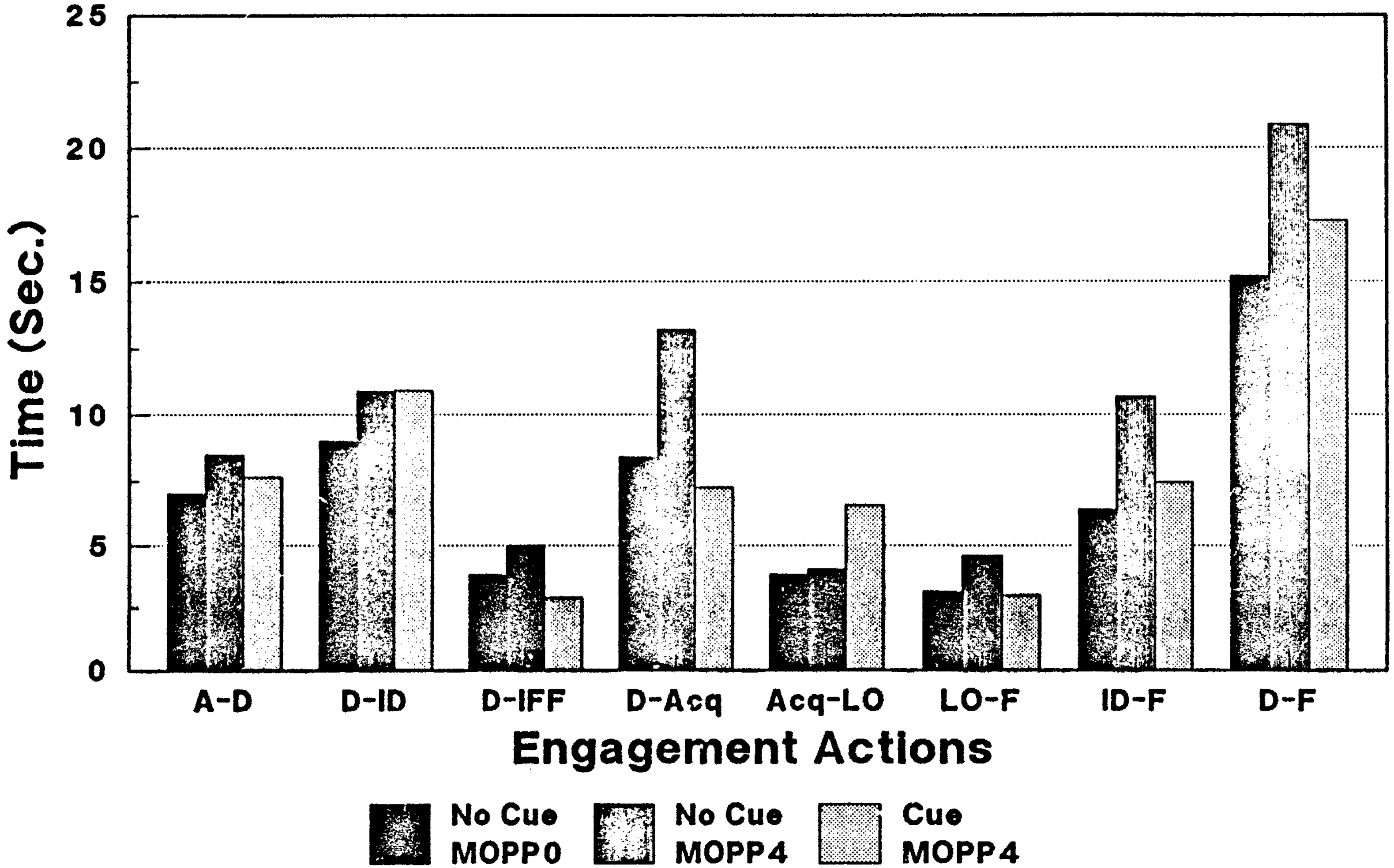

Figure 7. Time to perform engagement actions for rotary-wing targets: Effect of cuing on reduction of baseline MOPP4 decrement.

The results presented in this table show that wearing MOPP4 increases the duration of the engagement sequence during all critical periods for the baseline, no cue Sub-Experiment 1. The mean time from target available to detect was increased by 1.50 seconds. After the target had been detected, the mean time to identify the target was increased by 1.90 seconds. After the target had been detected and identified as hostile, the mean time to fire was increased by 4.30 seconds. This means that after the team chief had completely finished his part of the engagement sequence and had ordered the gunner to fire on a target which was hovering within range, the MOPP4-encumbered gunner required an additional 4.30 seconds to fire not required by the same gunner while in MOPP0. The mean time for a complete engagement (available to fire) was longer by 7.70 seconds for the MOPP4 condition. This is the difference between engagement times which approach acceptability and engagement times which are unacceptably long (for a discussion of Stinger training standards see Barber, 1990b; Drewfs & Barber, 1990).

The results presented in Table 22 also show that for the entire available-to-fire period the cue condition of MOPP4 was 4.07 seconds shorter than the comparable no cue condition of MOPP4—a reduction of the baseline MOPP4 decrement by 53 percent [No Cue MOPP4 - No Cue MOPP0 = 7.70 (baseline decrement); Cue MOPP4 - No Cue MOPP0 = 3.63; 7.70 - 3.63 = 4.07 (reduction in baseline decrement); 4.07 / 7.70 = 0.53 (proportion of baseline decrement reduced)].

In addition, two special Task Performance Measures were analyzed—one each for Scenarios 12 and 13. These are measures of the total time in seconds from target availability until the last action was performed on the third target. That is, each of these measures represents the total time taken to service all three simultaneous rotary-wing aircraft. It was hypothesized that this "time from available to last act" would be longer for the MOPP4 condition and shorter for the cue condition.

Table 23 presents the time from available to last act for Scenario 12 for the conditions of the experiment. Times were significantly longer in the MOPP4 condition (49.83 seconds) than in the MOPP0 condition (42.67 seconds) [$F(1, 22) = 3.93$, $p<.10$]. There was no effect of cuing [$F(1, 22) = 0.01$, $p>.10$] and no MOPP by cuing interaction [$F(1, 22) = 0.24$, $p>.10$].

Table 23

Scenario 12: Time from Available to Last Act in Seconds by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	43.70	49.10	41.64	50.57
<u>SD</u>	14.91	14.06	11.84	9.95
<u>N</u>	10	10	14	14

Table 24 displays the time from available to last act for Scenario 13 for the conditions of the experiment. There were no statistically significant differences for MOPP [$F(1, 22) = 1.44$, $p>.10$] or cuing [$F(1, 22) = 1.40$, $p>.10$], and no interaction between the two [$F(1, 22) = 0.96$, $p>.10$].

Table 24

Scenario 13: Time from Available to Last Act in Seconds by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	54.90	60.60	51.57	52.14
SD	10.43	13.98	12.89	15.79
N	10	10	14	14

Results for rotary-wing aircraft: SPMs. Rotary-wing Summary Performance Measures and associated analyses will only be presented in detail where there were statistically significant results. The mean overall percentage of aircraft detected was 98.88. The mean overall percentage of aircraft correctly identified (hostile plus friendly) was 70.83. The mean overall percentage of friendly aircraft correctly identified was 58.71. The overall mean fratricide rate was 35.63 percent.

Table 25 presents the percent hostile aircraft correctly identified by conditions. There was no statistically significant effect of MOPP level [$F(1, 25) = 0.07$, $p>.10$]. There was a significant decrease in performance as a function of cuing [$F(1, 25) = 3.84$, $p<.10$], with the percentage for the cued condition (74.91) being lower than that for the no cue condition (90.00). This result ran opposite to the hypothesis stated above and could not be explained. There was no interaction between MOPP and cuing [$F(1, 25) = 0.05$, $p>.10$].

Table 25

Rotary-Wing: Percent Hostile Aircraft Correctly Identified by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	90.10	89.90	76.00	73.82
SD	15.94	16.15	22.82	27.68
N	10	10	17	17

Table 26 displays percent hostile aircraft attrition as a function of MOPP level and presence or absence of cues. There was a statistically significant interaction between MOPP level and cuing [$F(1, 25) = 5.30$, $p<.05$]. Attrition was reduced substantially in the MOPP4 condition when there were no cues (accounting for the significant main effect of MOPP level [$F(1, 25) = 3.04$, $p<.10$]), and improved slightly when there were cues. There was no main effect of cues [$F(1, 25) = 0.28$, $p>.10$].

Table 26

Rotary-Wing: Percent Hostile Aircraft Attrition by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	83.30	63.30	67.65	70.41
SD	22.25	24.67	19.96	27.43
N	10	10	17	17

Table 27 presents the percent hostiles credited as killed prior to their releasing ordnance as a function of conditions of the experiment. (The ordnance release point for hostile RW aircraft was defined as 20 seconds from availability. That is, a hostile aircraft was assumed to be capable of releasing ordnance if not killed prior to 20 seconds from availability. In order to prevent ordnance release, the team must fire at the target early enough in the scenario to allow missile flight time to target within 20 seconds from availability.) The percentage of hostiles killed prior to ordnance release was significantly smaller during the MOPP4 condition (17.89) than during the MOPP0 condition (25.09) [$F(1, 25) = 2.96$, $p<.10$]. There was no significant effect of cues [$F(1, 25) = 2.05$, $p>.10$] and no interaction [$F(1, 25) = 1.73$, $p>.10$].

Table 27

Rotary-Wing: Percent Hostiles Killed Prior to Ordnance Release by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	22.70	10.00	27.47	25.77
SD	26.15	13.97	20.35	21.17
N	10	10	17	17

Table 28 displays the conditional probability of a credited kill given a fire (in units of percent) as a function of MOPP level and presence or absence of cues. Probability of kill was significantly lower during the MOPP4 condition (89.99) than during the MOPP0 condition (98.11) [$F(1, 25) = 3.26$, $p<.10$]. There was no effect of cuing [$F(1, 25) = 0.02$, $p>.10$] and no interaction between MOPP level and cuing condition [$F(1, 25) = 0.46$, $p>.10$].

Table 28

Rotary-Wing: Conditional Probability of Kill Given Fire (in Percent) by Conditions

Statistic	No Cue MOPP0	No Cue MOPP4	Cue MOPP0	Cue MOPP4
Mean	100.00	88.80	96.23	91.18
SD	0.00	12.06	10.15	25.07
N	10	10	17	17

Correlation of Vision Measures With Engagement Performance

Measures of visual sensitivity were correlated with selected measures of engagement performance separately for each sub-experiment. The four vision measures were foveal visual acuity, general contrast sensitivity, high frequency contrast sensitivity, and resting focus. These measures were chosen because past research showed them to be reliably correlated with FAAD engagement performance (Barber, 1990a). Visual acuity is an ordinal-level measure and is reverse scored, with lower scores representing better performance. General contrast sensitivity is the mean contrast sensitivity score for all five spatial frequencies. High frequency contrast sensitivity is the mean contrast sensitivity score for the two highest frequency gratings (12 and 18 cycles per degree). Contrast sensitivity is also an ordinal-level measure. Better performance is represented by higher scores. Resting focus is a ratio-level measure and is also reverse scored, with lower scores representing better performance. Mean, SD, and N are presented for the vision measures in Table 29 for both sub-experiments.

Table 29

Vision Scores for Team Chiefs for Both Sub-Experiments

Statistic	Baseline Sub-Experiment 1		Cuing Sub-Experiment 2	
	$\underline{N}$ = 8		$\underline{N}$ = 14	
	Mean	SD	Mean	SD
FA	15.13	3.18	16.00	4.08
CS	6.35	0.37	6.03	0.69
CSH	5.94	0.68	5.43	1.11
RF	10.64	0.90	10.06	1.12

FA = Foveal Acuity
CS = General Contrast Sensitivity
CSH = High Frequency Contrast Sensitivity
RF = Resting Focus

Six engagement tasks were selected for correlation because they require a substantial admixture of visual processing for their performance. They were FW detection range, FW identification range, percent FW correctly identified, RW available to detect time, RW detect to identify time, and percent RW correctly identified. A Stinger team detects all targets with the unaided eye (FM 44-18-1). For a Stinger team in Weapons Control Status Tight all targets are identified by the team chief using his eyes aided with binoculars (FM 44-18-1). Past research has shown that these six engagement tasks correlate with the four vision measures described above (Barber, 1990a). Correlations were performed separately for conditions of MOPP0 and MOPP4.

All correlations were performed on visual scores obtained from the team chiefs because they were primarily responsible for detection and exclusively responsible for identification. In addition, using similar participants, equipment, and procedures Barber (1990a) showed that the detection and identification tasks correlated with these same vision measures, while the specifically gunner tasks of weapon acquisition and tracking did not. Also using similar participants, equipment, and procedures Gast and Johnson (1990) showed that the identification performance of Stinger team chiefs predicted both total engagement time and team effectiveness (i.e., "kills"). For these reasons the decision was made to limit the analysis to team chiefs only.

A total of 96 correlation coefficients were run (4 vision scores x 6 engagement tasks x 2 conditions of MOPP x 2 sub-experiments = 96). A one-tailed test was chosen, where better vision scores were predicted to improve engagement performance. An alpha level of five percent was chosen. Hence, 4.8 statistically significant correlation coefficients would have been expected by chance alone (0.05 x 96 = 4.8).

Nine correlations were statistically significant. These results are presented in Table 30 by MOPP level and sub-experiment. Eight of the nine significant correlations involved the detection task (FW detection range, RW available to detect time). Team chiefs with better visual sensitivity were able to detect aircraft earlier and at greater range. With a single noted exception, there was no evidence in these data that individual differences in visual capability related to the identification task.

Table 30

Statistically Significant Correlations Between Visual Sensitivity and Selected Engagement Tasks

<u>Sub-Experiment 1 (Baseline): MOPP0</u>
RW percent correct ID with RF (Pearson $r = -.68$, $N = 10$, $p < .05$)

<u>Sub-Experiment 1 (Baseline): MOPP4</u>
FW detect range with FA (Spearman <u>rho</u> = $-.62$, $N = 8$, $p = .05$)

<u>Sub-Experiment 2 (Cuing): MOPP0</u>
FW detect range with FA (Spearman <u>rho</u> = $-.44$, $N = 14$, $p = .05$)
RW av. to detect time with FA (Spearman <u>rho</u> = $.46$, $N = 17$, $p < .05$)
RW av. to detect time with CS (Spearman <u>rho</u> = $-.39$, $N = 17$, $p = .05$)
RW av. to detect time with RF (Pearson $r = .48$, $N = 17$, $p < .05$)

<u>Sub-Experiment 2 (Cuing): MOPP4</u>
RW av. to detect time with FA (Spearman <u>rho</u> = $.48$, $N = 17$, $p < .05$)
RW av. to detect time with CS (Spearman <u>rho</u> = $-.57$, $N = 17$, $p < .01$)
RW av. to detect time with CSH (Spearman <u>rho</u> = $-.45$, $N = 17$, $p < .05$)

FA = Foveal Acuity
CS = General Contrast Sensitivity
CSH = High Frequency Contrast Sensitivity
RF = Resting Focus

<u>Stress and Workload</u>

<u>Stress</u>. The Mann-Whitney <u>U</u> test for between-groups comparisons and the Wilcoxon <u>T</u> test for within-group comparisons (Bruning & Kintz, 1977) were used to analyze the stress data reported during Sub-Experiment 1 and Sub-Experiment 2. Tables 31 through 34 display means, standard deviations (<u>SD</u>), number of observations (<u>N</u>), and results of the statistical analyses for the between- and within-group comparisons.

Because there were no significant differences in reported stress levels between Sub-Experiment 1 and Sub-Experiment 2 (see Table 31) or between the team chiefs' and gunners' ratings (see Table 32), these data were combined for further analysis.

Table 31

Independent Groups Mann-Whitney *U* Test Analysis of Stress Ratings Given in Sub-Experiment 1 and Sub-Experiment 2

	Sub-Experiment 1	Sub-Experiment 2	Results
	Pretest MOPP0		
Mean	34.83	35.82	$U = 380.0$, $p > .05$
SD	6.95	9.21	
N	24	34	
	Posttest MOPP0		
Mean	35.91	35.85	$U = 364.0$, $p > .05$
SD	10.99	10.06	
N	22	34	
	Pretest MOPP4		
Mean	45.55	44.56	$U = 329.0$, $p > .05$
SD	10.56	12.40	
N	20	34	
	Posttest MOPP4		
Mean	42.65	41.64	$U = 253.5$, $p > .05$
SD	9.92	12.31	
N	20	28	

Table 32

Independent Groups Mann-Whitney U Test Analysis of Stress Ratings Given by Team Chiefs and Gunners

	Team Chief	Gunner	Results
	Pretest MOPP0		
Mean	35.42	35.41	$U = 339.5, p > .05$
SD	8.97	8.54	
N	26	27	
	Posttest MOPP0		
Mean	35.65	34.09	$U = 253.0, p > .05$
SD	11.06	9.23	
N	23	23	
	Pretest MOPP4		
Mean	45.19	45.04	$U = 340.0, p > .05$
SD	10.93	12.92	
N	26	27	
	Posttest MOPP4		
Mean	43.35	41.39	$U = 243.0, p > .05$
SD	12.01	10.84	
N	23	23	

As expected, the MOPP4 stress ratings were significantly greater than the MOPP0 ratings both pretest and posttest (see Table 33).

Table 33

Related Groups Wilcoxon *T* Test Analysis of MOPP0 and MOPP4 Stress Ratings

	MOPP0	MOPP4	Results
		Pretest	
Mean	35.42	45.11	$T = 84$, $p < .05$
SD	8.67	11.67	
N	53	53	
		Posttest	
Mean	34.87	42.37	$T = 179$, $p < .05$
SD	10.11	11.35	
N	46	46	

Analysis of the ratings given before and after MOPP0 and MOPP4 trials revealed no significant differences between the levels of stress reported at the beginning and at the end of trials (see Table 34). Perceived stress, therefore, remained constant over trials.

Table 34

Related Groups Wilcoxon _T_ Test Analysis of Stress Ratings Given Prior to and at the Conclusion of MOPP0 and MOPP4 Trials

	Pretest	Posttest	Results
		MOPP0	
Mean	35.43	35.88	$T = 650.0$, $p > .05$
_SD_	8.45	10.34	
_N_	56	56	
		MOPP4	
Mean	45.98	42.69	$T = 369.5$, $p > .05$
_SD_	11.94	11.81	
_N_	48	48	

Workload. After each trial for record, participants in Sub-Experiments 1 and 2 rated workload using the NASA TLX scale. The workload ratings collected during this research were used in the relative sense, comparing whether the MOPP0 or the MOPP4 condition was perceived as having higher workload. The workload data were subjected to a mixed three factor repeated measures Analysis of Variance (Norusis, 1986). Cuing condition (cue, no cue) was the between-subjects factor. MOPP (MOPP0, MOPP4) and scenario difficulty (low, medium, high) were the within-subjects factors.

There was no main effect of cue condition [$F(1, 20) = 0.22$, $p>.05$] indicating that reported workload was equivalent in the sub-experiments. As expected, however, there was a main effect of MOPP [$F(1, 20) = 23.56$, $p<.001$] with workload ratings being significantly higher for the MOPP4 condition. There was also a significant scenario effect [$F(2, 40) = 9.26$, $p<.001$] which is evidence that participants responded differentially to the scenario difficulty with greater workload being assigned to the more demanding scenarios. None of the interactions included in this analysis were significant at the five percent level [cue x MOPP, $F(1, 20) = 0.69$, $p>.05$; cue x scenario, $F(2, 40) = 0.37$, $p>.05$; MOPP x scenario, $F(2, 40) = 3.10$, $p>.05$; cue x MOPP x scenario, $F(2, 40) = 1.82$, $p>.05$].

Because the actions performed by the team chief and gunner during the engagement sequence are different, separate analyses were performed on the workload ratings given by these individuals to identify differential patterns of assessing workload, should they exist. Team chief and gunner ratings were analyzed in mixed three factor repeated measures ANOVAs (2 cue x 2 MOPP x 3 scenario difficulty). Generally the analyses of the team chief and gunner data yielded the same pattern of results seen in Sub-Experiments 1 and 2. Once again, there was no main effect of cue for either the team chief or gunner [TC, $F(1, 20) = 0.18$, $p>.05$; gunner, $F(1, 20) = 0.21$, $p>.05$], but the MOPP effect [TC, $F(1, 20) = 18.10$, $p<.001$; gunner, $F(1, 20) = 17.42$, $p<.001$] and the scenario difficulty effect [TC, $F(2, 40) = 7.21$, $p<.002$; gunner, $F(2, 40) = 10.15$, $p<.001$] were significant as in the sub-experiments analysis. The only exception to the replicated pattern of results for the separate analyses was a significant interaction of MOPP and scenario difficulty seen in the analysis of the team chiefs' workload data [$F(2, 40) = 3.33$, $p<.05$].

Figure 8 displays the three MOPP x scenario difficulty interactions for the analyses described in this section (Sub-Experiments 1 and 2, team chiefs, and gunners). The significant interaction of MOPP and scenario difficulty yielded by the team chiefs' ratings result from the fact that the workload ratings given by the team chiefs while wearing MOPP4 were highest for the medium difficulty scenarios. This pattern of response differs from that given by the gunners. The magnitude of gunner workload ratings corresponded directly to the difficulty level of the scenarios. Thus, the team chiefs but not the gunners gave the highest workload ratings to the engagement of single fixed-wing aircraft (medium difficulty) but only while in MOPP4.

Table 35 shows the comparison between morning workload ratings and afternoon workload ratings as a function of MOPP level and scenario difficulty. Of the six comparisons (two conditions of MOPP x three conditions of scenario difficulty = six comparisons) three were statistically significant. Although only half of the means differed significantly from each other, it is interesting to note that reported workload was always greater in the morning, regardless of MOPP condition. This finding suggests that experience in the test situation and in MOPP gear dissipates the magnitude of perceived workload over the course of trials.

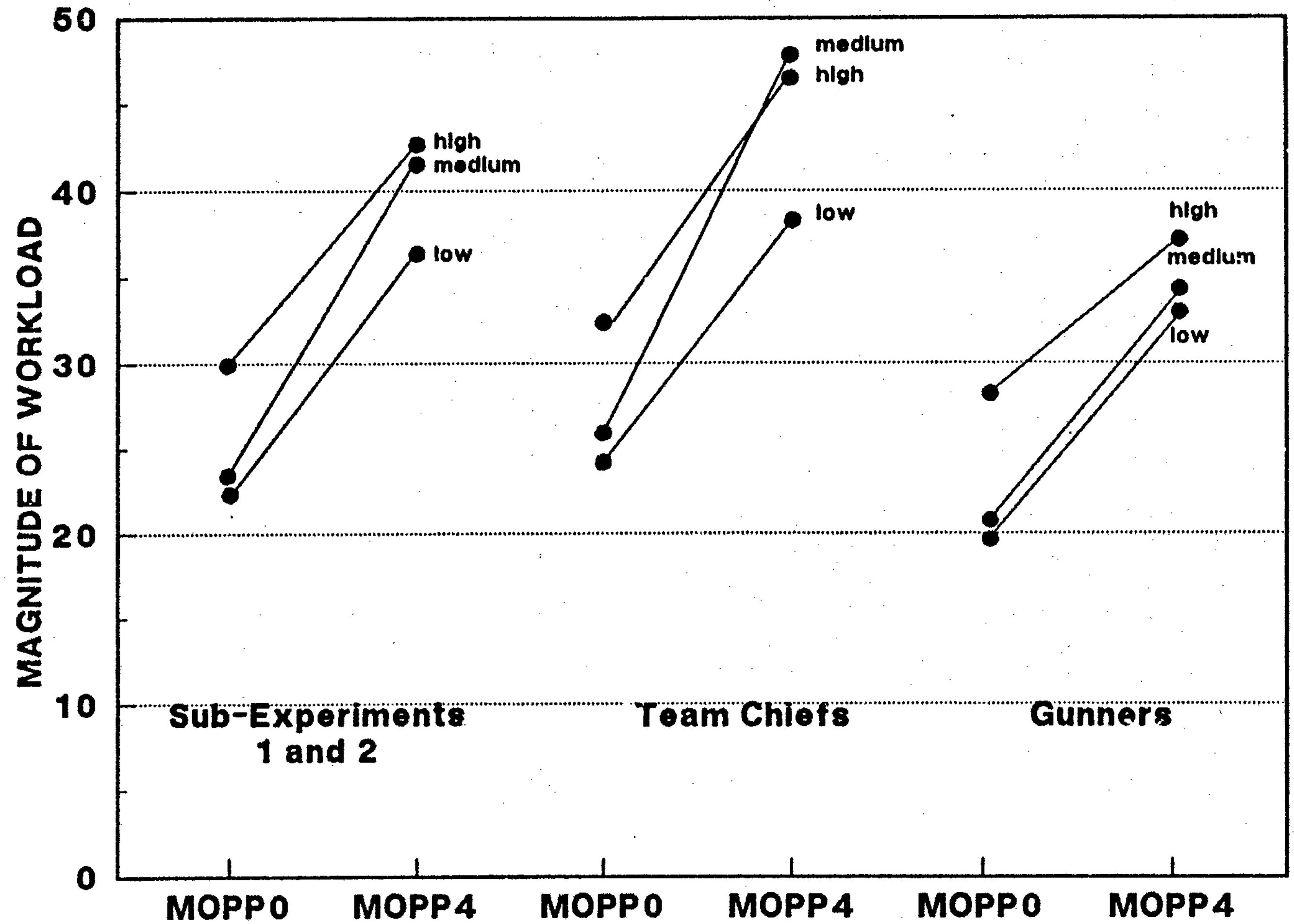

Figure 8. MOPP x scenario difficulty interactions for the sub-experiments, team chief, and gunner data.

Table 35

Independent Groups Student's *t* Test Analysis of MOPP0 and MOPP4 Workload Ratings Given in the Morning and in the Afternoon

	Morning	Afternoon	Results
	Low Difficulty Scenarios MOPP0		
Mean	25.58	19.47	$t = 1.44$, $p > .05$
SD	17.25	14.04	
N	34	24	
	Low Difficulty Scenarios MOPP4		
Mean	39.60	33.57	$t = 1.28$, $p > .05$
SD	15.41	19.50	
N	24	30	
	Medium Difficulty Scenarios MOPP0		
Mean	29.08	20.37	$t = 2.19$, $p < .025$
SD	15.10	14.91	
N	30	24	
	Medium Difficulty Scenarios MOPP4		
Mean	44.29	38.55	$t = 1.02$, $p > .05$
SD	16.33	23.03	
N	24	24	
	High Difficulty Scenarios MOPP0		
Mean	35.89	26.09	$t = 1.99$, $p < .05$
SD	20.22	16.12	
N	34	24	
	High Difficulty Scenarios MOPP4		
Mean	48.81	36.59	$t = 2.06$, $p < .025$
SD	16.24	24.72	
N	24	24	

Discussion

Engagement Performance (Sub-Experiments 1 and 2)

Fixed-wing aircraft. Overall, the effect of wearing MOPP4 was to delay engagement performance by approximately one kilometer. This effect was largest early in the engagement sequence (detect, IFF, ID) and smallest late in the engagement sequence (lock-on, fire). The engagement step most affected by wearing MOPP4 was identification range where the overall MOPP0 - MOPP4 difference was 2.16 kilometers. Interestingly, the entirety of the degradation due to MOPP4 cannot be accounted for simply by positing that the degradation was present at detection and this initial difference delayed performance throughout the remainder of the engagement sequence in turn. For the degradation present at identification was approximately 2.5 times as great as that at detection. Clearly, wearing MOPP4 lowered identification efficiency in addition to the harm already done to detection efficiency.

Specifically, what was it about wearing MOPP4 that caused the degradation in FW engagement performance? The impairment in detection range was most likely caused by the restricted field of view encountered when wearing the mask (Bensel, et al., 1987; Kobrick & Sleeper, 1986). This interpretation is supported by the fact that cues, which effectively reduce the search sector, improved detection range in the MOPP4 condition (see Table 5).

The decrement in IFF range could have been caused by the difficulty gunners reported (see Appendix B) in attempting to track flying aircraft with the Stinger sight reticle while wearing the mask. Gunners could not interrogate the aircraft until it was within their sight reticle, and putting the aircraft within the sight reticle was more difficult and took longer while wearing the mask.

The decrement in identification range could have been caused by the difficulty team chiefs reported (see Appendix B) in attempting to identify flying aircraft with binoculars while wearing the mask. It has already been reported (Harrah, 1985) that the mask-binocular interface produces a narrow field of view. This narrow field of view makes tracking a maneuvering, flying aircraft difficult. In addition to this tracking problem, team chiefs reported double images and visual disorientation—another problem. In an attempt to alleviate the double-image problem, team chiefs closed one eye or otherwise used only one optic of the binoculars—causing another problem. It is, therefore, a reasonable assumption that wearing the mask was the primary cause of the performance degradation shown for FW aircraft in this experiment.

Overall, the Summary Performance Measures were virtually unaffected by wearing MOPP4, even though sometimes substantial differences were shown for Task Performance Measures. Results such as these have repeatedly been seen by us in the past (e.g., Barber, 1990b; Drewfs & Barber, 1990; Johnson, Barber, & Lockhart, 1988) and are caused by differences in the nature of the measures themselves. To understand these differences a word must be said about the "window of engagement." The engagement window begins when the target first becomes available for engagement by the team and ends when the target ceases to be available. SPMs measure the probability of a particular event occurring during the engagement window, whereas TPMs measure specifically when within the window these events occur.

This explains why the SPMs were so often unaffected by the action of the independent variable (i.e., MOPP0 versus MOPP4). SPMs measure whether or not a particular engagement event occurred, not when it occurred. As an example consider the case of identification. The SPM "percent aircraft correctly identified" measured correct ID for the engagement window. It was not significantly affected by MOPP level—varying around 57 percent correct for both conditions. That is, percent correct ID at the end of the engagement window was constant. However, precisely where within the window these ID responses were made did vary significantly—being 2.16 kilometers later for the MOPP4 condition. That is, the team chiefs showed the same overall percent correct identification performance, but they consistently made their responses later when wearing MOPP4. Thus, this paucity of significant results in terms of SPMs should not be interpreted to mean that there was no effect of MOPP4 upon Stinger team performance.

The overall effect of adding precise visual cues was to improve engagement performance by 2.21 kilometers. The range of every Task Performance Measure was significantly improved. This improvement varied from a low of 1.19 kilometers for detection to a high of 2.98 kilometers for acquisition. The improvement in performance more than doubled after the detection event, suggesting that the effect of cues was not limited only to increasing detection range. The SPMs, however, were unaffected by the addition of cues (see discussion of SPMs above).

It will be remembered that the purpose for the addition of cues (i.e., Sub-Experiment 2) was to evaluate their usefulness in reducing the degradation attributable to wearing MOPP4. This potential "fix" appeared to be successful. Compare the performance for the cue condition of MOPP4 with that for the no cue condition of MOPP0 (see Figure 4). Not only was the MOPP4 condition not degraded relative to the MOPP0 condition, it was superior. Over all six engagement actions, the MOPP4 condition was superior by a mean range of 1.30 kilometers. Again, the improvement shown for the cue condition was not limited only to the detect event.

Rotary-wing aircraft. Overall, the effect of wearing MOPP4 was to increase the time required for a complete engagement (target available to fire) by 25 percent. Extra time was required for all critical engagement periods: available to detect, detect to identify, and identify to fire. Overall, available to detect time was increased by 10.7 percent, detect to identify time by 17.8 percent, and identify to fire time by 54 percent. Wearing MOPP4 affected both the team chief and the gunner. The engagement period detect to identify was entirely dependent upon the time taken by the team chief, using binoculars, to identify the target. The engagement period identify to fire was entirely dependent upon the gunner. Remember, the gunner had already had the target detected and identified as hostile, he had been given a command to fire, the target was hovering within range, and the gunner had already shouldered his Stinger. Yet, it still took him 54 percent more time to complete the engagement while in MOPP4. The effect of wearing MOPP4 was to increase the time required for all engagement actions by both members of the team. There was no evidence from this experiment that the effects of wearing MOPP4 were limited to a single "bottleneck" in the engagement sequence.

Specifically, what was it about wearing MOPP4 that caused the degradation in RW engagement performance? The increase in time from available to detect was most likely caused by the restricted field of view of the mask (Bensel et al., 1987; Kobrick & Sleeper, 1986). As with the FW aircraft, this interpretation is supported by the fact that cues, which effectively reduce the search sector, shortened available to detect time in the MOPP4 condition (see Table 14).

The increase in detect to identify time could have been caused by the difficulty team chiefs reported (see Appendix B) in attempting to use the binoculars with the mask. Team chiefs reported a double-image problem with consequent visual disorientation and "solved" it by using only one eye. This could have delayed identification of the RW aircraft which, being 3.5 kilometers distant, were not identifiable without magnification.

At least part of the increase in time from identify to fire could have been caused by the difficulties reported by gunners (see Appendix B) in attempting to use the Stinger sight reticle while wearing the mask. Gunners reported difficulty acquiring aircraft in the reticle while wearing the mask. Perhaps more importantly, gunners reported difficulty inserting superelevate and lead angle because the mask prevented them from seeing the superelevate and lead reticles in the sight. This interpretation is supported by the significant increase in times from lock-on to fire shown for the MOPP4 condition (see Figure 5 and Table 19). Insertion of the superelevate and lead angle takes place between lock-on and fire. Thus, as in the case of the FW aircraft, it is a reasonable assumption that the primary cause of the performance degradation shown for RW aircraft in this experiment was the mask.

As with the fixed-wing results, the SPMs were largely unaffected by the level of MOPP worn. Where significant results were found they were entirely consistent with the TPMs. Under conditions of MOPP4 the percentage of hostiles killed was lower, the percentage of hostiles killed prior to ordnance release was lower, and the conditional probability of kill given a fire event was lower. These results can all be explained in terms of the increased time required for engagements in MOPP4. The more time the engagement sequence requires, the greater the probability that the hostile aircraft will have released its ordnance and then have returned to its defilade position, thereby being unavailable to kill.

Overall, the effect of precise visual cues on the engagement of RW aircraft was to reduce total time by a modest 7.6 percent. Why was the effect of cues large for the FW scenarios but small for the RW scenarios? Cues will be more helpful the more difficult or ambiguous is the stimulus environment. The RW environment was simpler and more stable than that of the FW. There were a total of six static RW aircraft, two each at three clock azimuth positions. They were all within visual (and Stinger) range and were clearly detectable once raised during a scenario. The FW aircraft, by comparison, did not occupy static positions but flew in from out of visual (and Stinger) range. The cues effectively narrowed the search sector and thereby allowed the FW aircraft to be detected at greater range (c.f., Wokoun, 1960). The Summary Performance Measures were unaffected by the presence of cues.

As in the case of the fixed-wing scenarios, the purpose for the addition of cues (i.e., Sub-Experiment 2) was to evaluate their usefulness in reducing the degradation attributable to wearing MOPP4. This potential "fix" appeared to be at least partially successful. As shown in Table 22, the addition of cues returned 53 percent of the engagement time lost to MOPP4 in the baseline sub-experiment. It is to be expected that cues would be even more helpful in a more difficult or ambiguous target environment.

Correlation of Vision Measures With Engagement Performance

The detection event correlated significantly with measures of visual sensitivity (see Table 30). This result was consistent with recent findings (Barber, 1990a). Given the visual nature of the engagement tasks chosen for correlation, as well as the Barber results, it was expected that many more significant correlations—especially between vision and identification—would emerge. It is assumed that methodological considerations limited these results. Barber's sample size was 138, while in this experiment the sample size varied from 8 to 17. In addition, Barber's sample covered a broader range of Forward Area Air Defense MOSs.

Stress and Workload

Analyses of the stress and workload data from Sub-Experiments 1 and 2 produced the expected results. Reported stress ratings were significantly higher when the Stinger teams wore MOPP4 than when they wore MOPP0. Also, workload ratings were significantly greater when teams performed the engagement sequence in the chemical protective ensemble than when executing the same tasks while wearing the battle dress uniform alone. The greater levels of stress and workload reported while wearing MOPP4 were not surprising given the encumbering nature of the protective clothing.

It was somewhat surprising at first glance, however, that significant differences in stress and workload ratings between Sub-Experiments 1 and 2 did not emerge. It might have been expected that the cuing information which so dramatically improved Stinger performance would have also reduced the levels of stress and workload, but they were statistically equivalent in the cue and no cue sub-experiments. A different set of results might be predicted should the same Stinger teams perform in both the cue and no cue sub-experiments, circumstances which would allow them to compare stress and workload under varying conditions.

As stated above, Stinger teams reported greater workload while in the MOPP ensemble. While each piece of the protective gear contributed to the elevated workload, the mask appeared to be the source of the most serious problems for the crews (see Appendix B). The team chief was able to use his binoculars only with difficulty while wearing the mask. Not only did the binoculars slide on the surface of the M40 eyepieces, they also significantly reduced the team chief's field of view. Likewise the eyepieces of the mask reduced the gunner's field of view when he placed his eye to the Stinger sight. Although the rubber gloves initially interfered with manual dexterity to some extent (see Appendix B), they did not appear to create significant problems for either the team chief or the gunner. The overgarment and overboots were reported to produce discomfort, but they did not seem to present significant engagement problems for teams.

The results of the ANOVAs performed on the sub-experiments, team chief, and gunner workload data yielded virtually identical findings. There were no differences in reported workload as a function of cue or no cue. MOPP4 produced significantly higher levels of workload. Workload increased as scenario difficulty increased. With but one exception, none of the interactions were significant at the five percent level. That exception was the team chief MOPP by scenario difficulty interaction. For team chiefs only, workload was greater during the medium difficulty scenarios than during high difficulty scenarios. This interaction of MOPP gear and scenario difficulty is explained by an examination of the types of aircraft used in the various scenarios.

Low difficulty scenarios were composed of single, scale-model, rotary-wing aircraft which ascended and hovered at fixed locations. Medium difficulty scenarios consisted of single, scale-model, remotely-piloted, fixed-wing aircraft moving at speeds and ranges adjusted to approximate the actual speeds and ranges of full-scale aircraft. High difficulty scenarios contained either multiple, scale-model, rotary-wing aircraft popping-up from fixed locations or a single rotary-wing and a single fixed-wing aircraft appearing simultaneously. When Stinger teams were not in MOPP4, the magnitude of workload assigned to these scenarios corresponded directly to the difficulty level of the scenario. However, the medium difficulty scenarios became the source of the greatest workload for the team chief when he was wearing the chemical protective ensemble. The fixed-wing aircraft presented during these engagements required the team chief to identify rapidly moving and maneuvering targets using binoculars in concert with the mask--a situation described by the team chiefs as creating performance difficulties (see Appendix B). Although the same mask-binocular interface problems existed for the low and high difficulty scenarios, the workload requirements were generally less because the targets were, with one exception, static and did not present the same tracking demands for the team chiefs.

It is reasonable to ask why these scenarios were not also perceived as being more difficult by the gunner. Like the team chief, he too had to track a rapidly moving and maneuvering target while wearing a mask. Unlike the team chief, however, the gunner had more time available to perform his job. The increased time was a result of the interval after detection during which the team chief must make a positive visual identification of the aircraft. This period afforded the gunner time to locate, track, and acquire the aircraft. Therefore, the gunner was not working under the same time pressure as the team chief and as such did not experience a corresponding workload. Time pressure is one of the defining characteristics of workload (e.g., Christ, Bulger, Hill, & Zaklad, 1990; NASA-Ames, 1986) and was one of the components of workload measured by the TLX questionnaire.

It should be noted, here, that the scenarios used in this experiment were calibrated for difficulty based upon years of research employing hundreds of air defenders of many different MOSs (Barber, 1990b; Drewfs & Barber, 1990). However, <u>none</u> of this earlier research employed participants wearing the MOPP4 chemical protective ensemble.

Some evidence that adaptation to the test situation and to wearing the chemical protective ensemble was taking place can be inferred from examination of the morning and afternoon workload means for the various scenarios and MOPP conditions. As seen in Table 35, the afternoon workload means were lower than the morning means in every instance. Although they were not all significantly different from each other, a clear pattern of workload reduction emerged during the afternoon sessions. It is possible that the engagement task was perceived as being easier after experience in the test situation.

All participants in both sub-experiments finished the sequence of MOPP4 engagement trials uneventfully. No individual needed to remove his protective gear during the sequence nor did anyone request to be removed from the experiment. Although two soldiers expressed apprehension about experiencing claustrophobia while in MOPP gear, their concerns were not realized. Perhaps because Operations Desert Shield and Desert Storm occurred concurrently with this research, we benefitted by having strongly motivated individuals as participants. These soldiers expressed the opinion that they would be sent to the Middle East as soon as they graduated from AIT and, in fact, at least some of them were sent.

Conclusions

Engagement performance of novice Stinger teams was degraded by wearing the MOPP4 chemical protective ensemble.

Engagement performance was improved by the addition of precise visual cues such as are expected to be available in the form of the Enhanced Hand-Held Terminal Unit component of the FAAD C2I network. Use of these cues substantially reduced the degradation due to wearing MOPP4.

Detection performance of Stinger team chiefs, both in MOPP0 and MOPP4, was correlated with several measures of visual sensitivity.

Reported stress levels were higher when Stinger teams wore MOPP4 than MOPP0.

Reported workload levels were higher in MOPP4 than in MOPP0.

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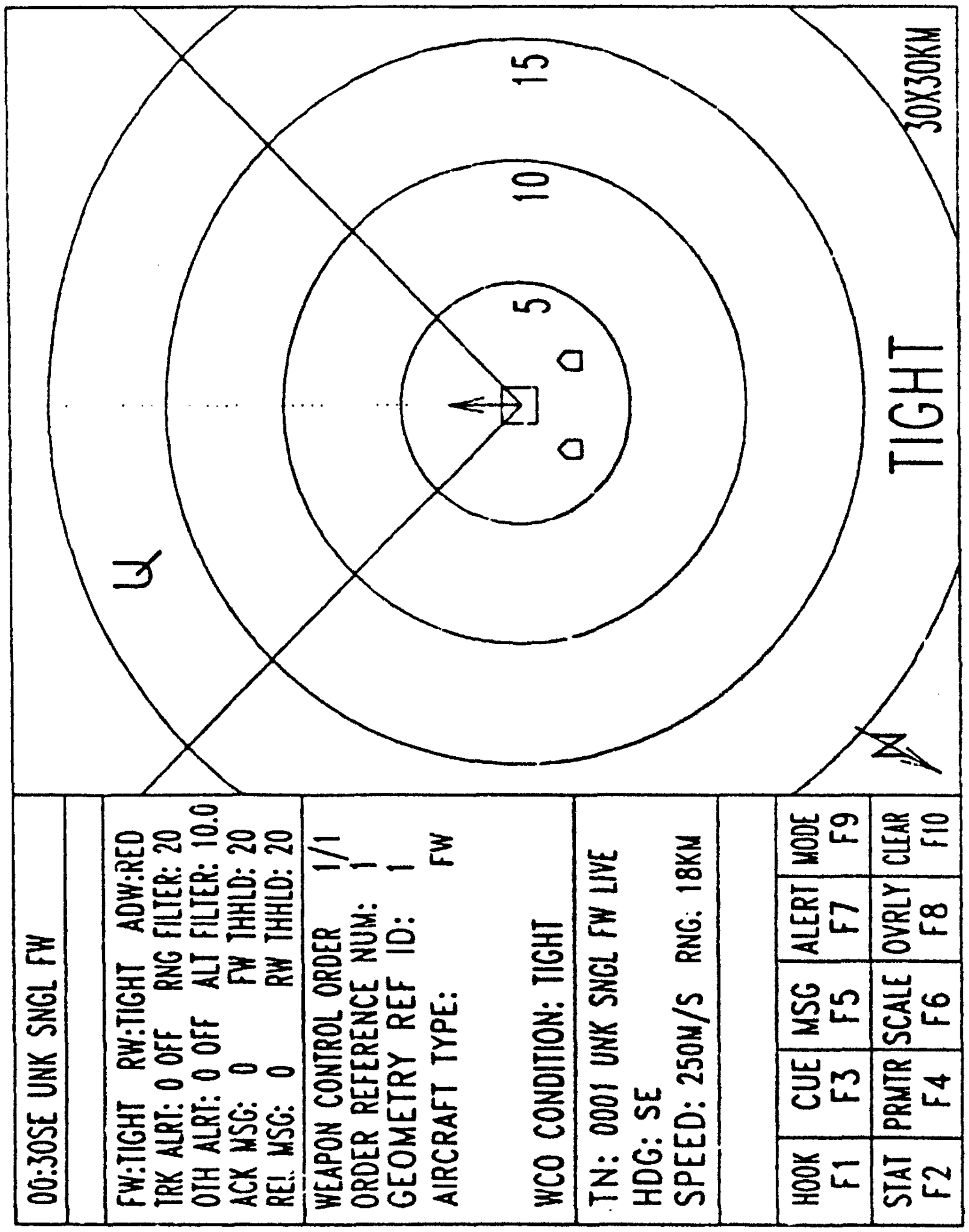
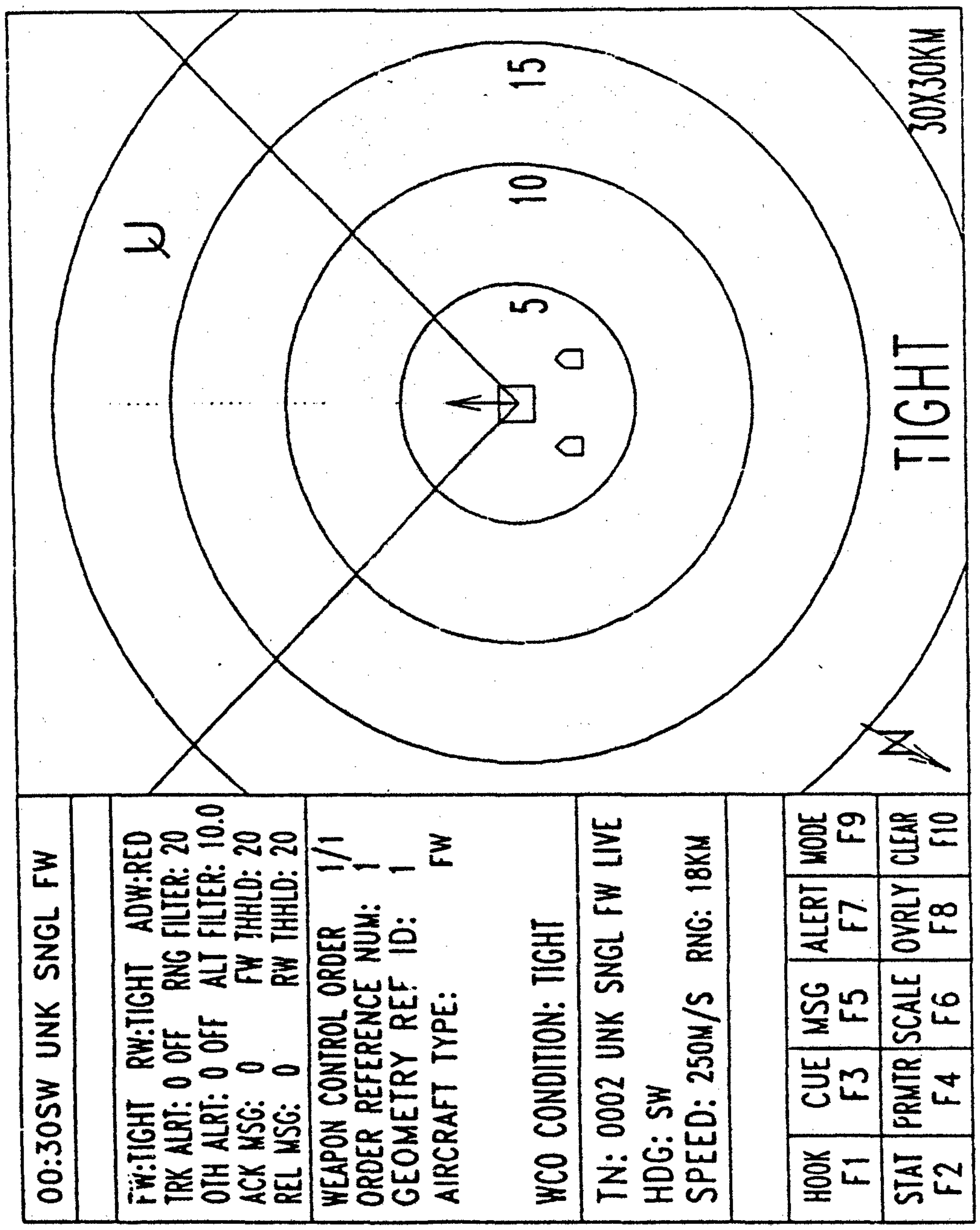
Appendix A

EHTU Cue Display Screens

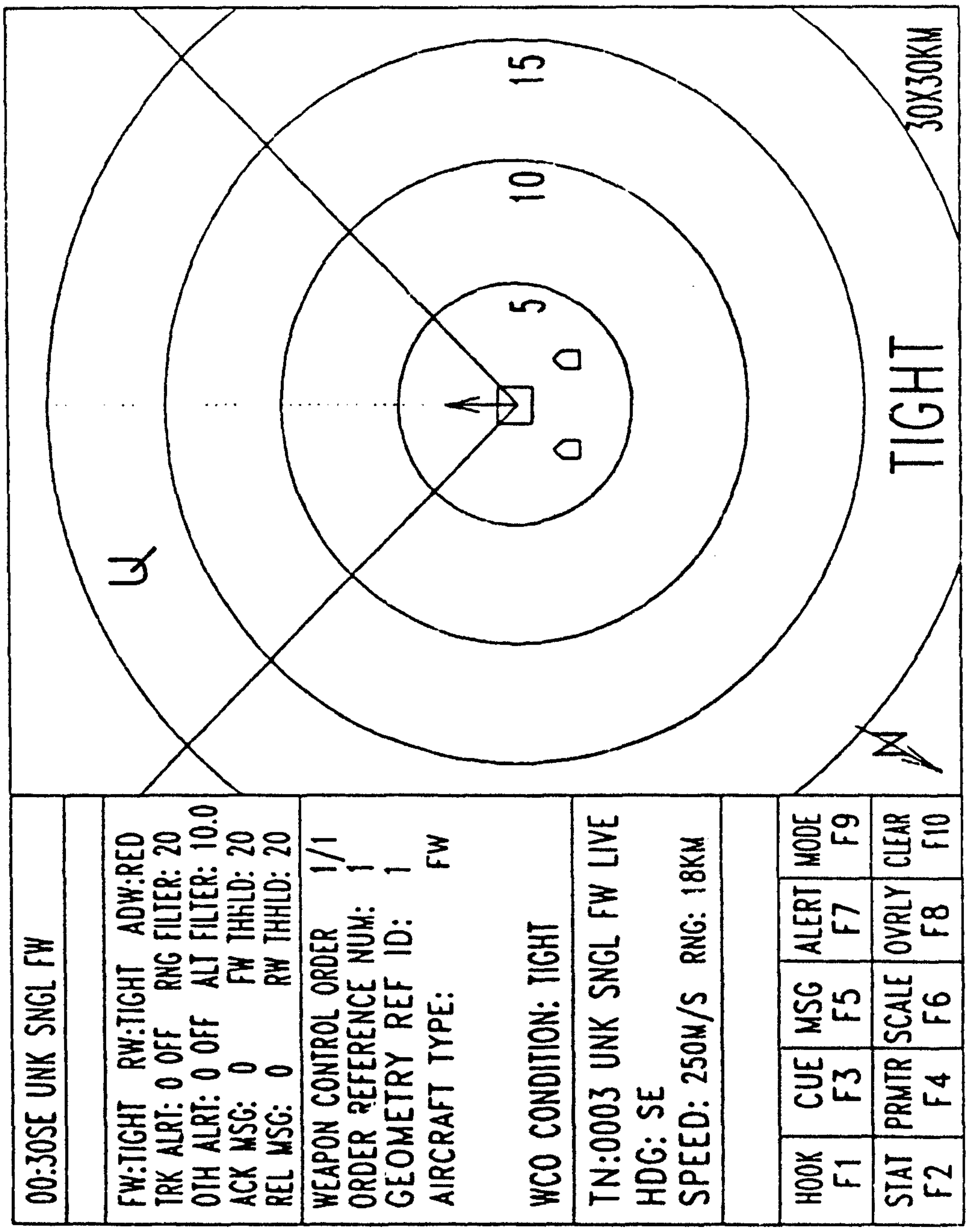
[NOTE: All displays have been reduced 29% from the actual size used in the experiment in order to meet USARI publication format.]



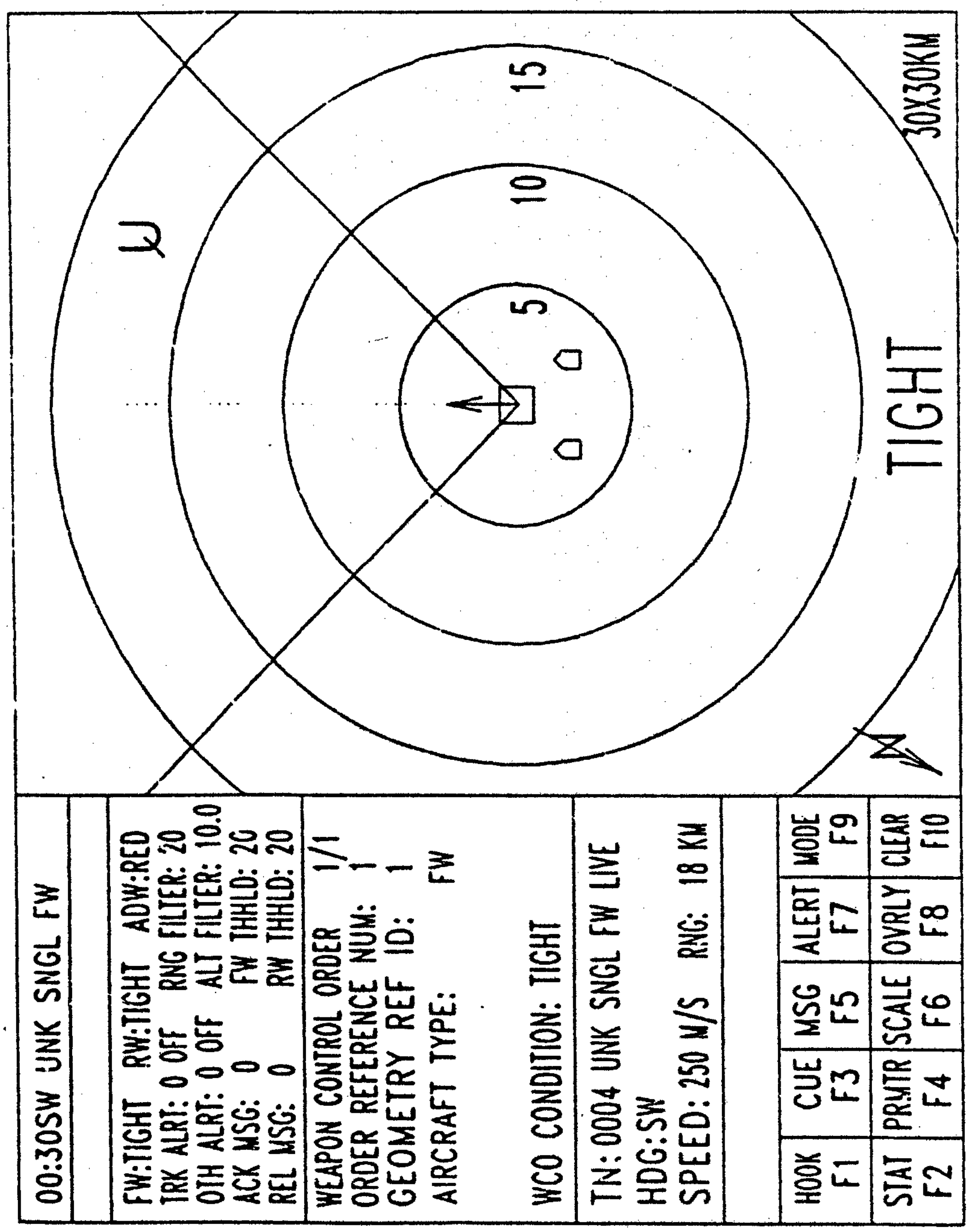
EHTU cue display for Scenario 1



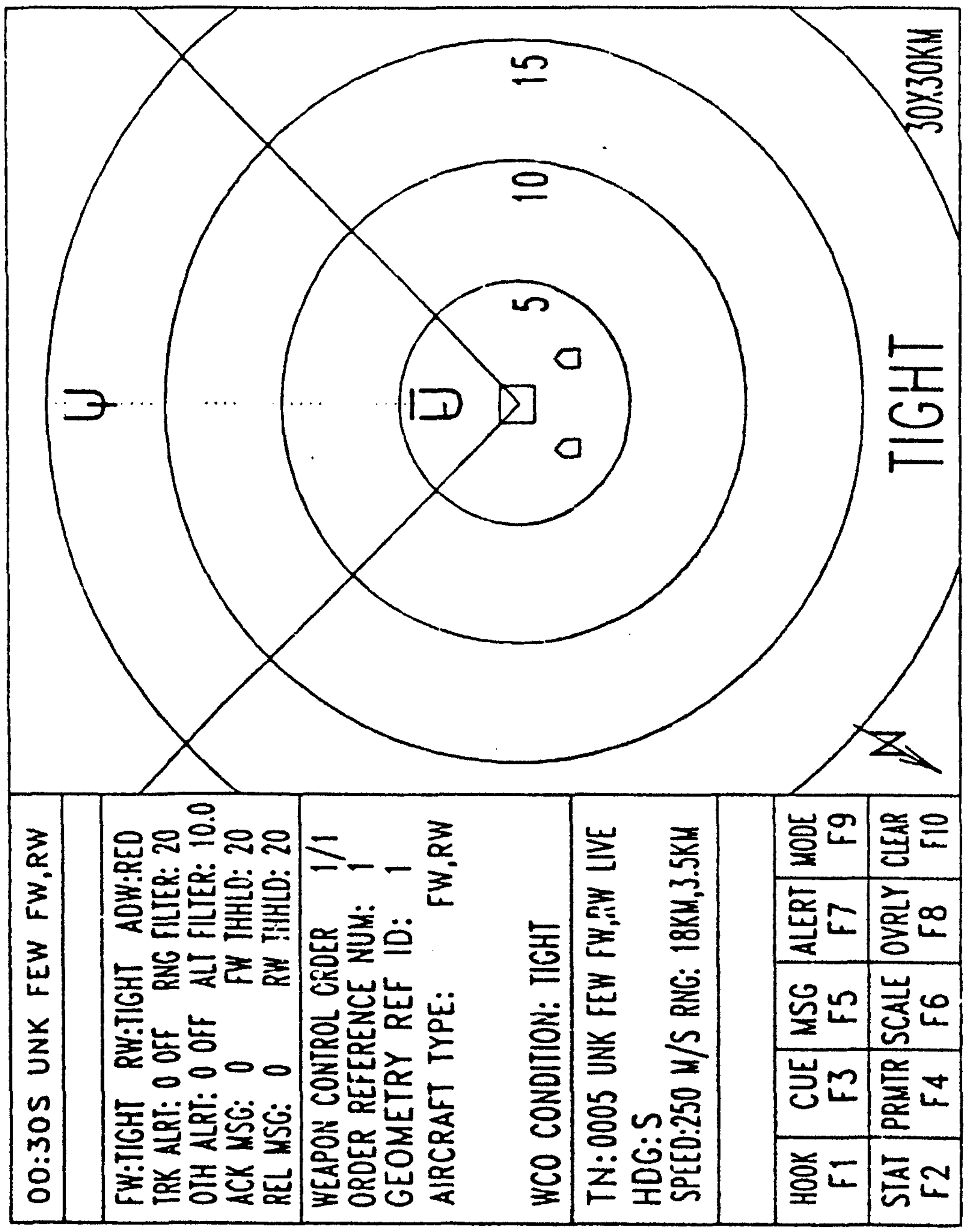
EHTU cue display for Scenario 2



EHTU cue display for Scenario 3



EHTU cue display for Scenario 4



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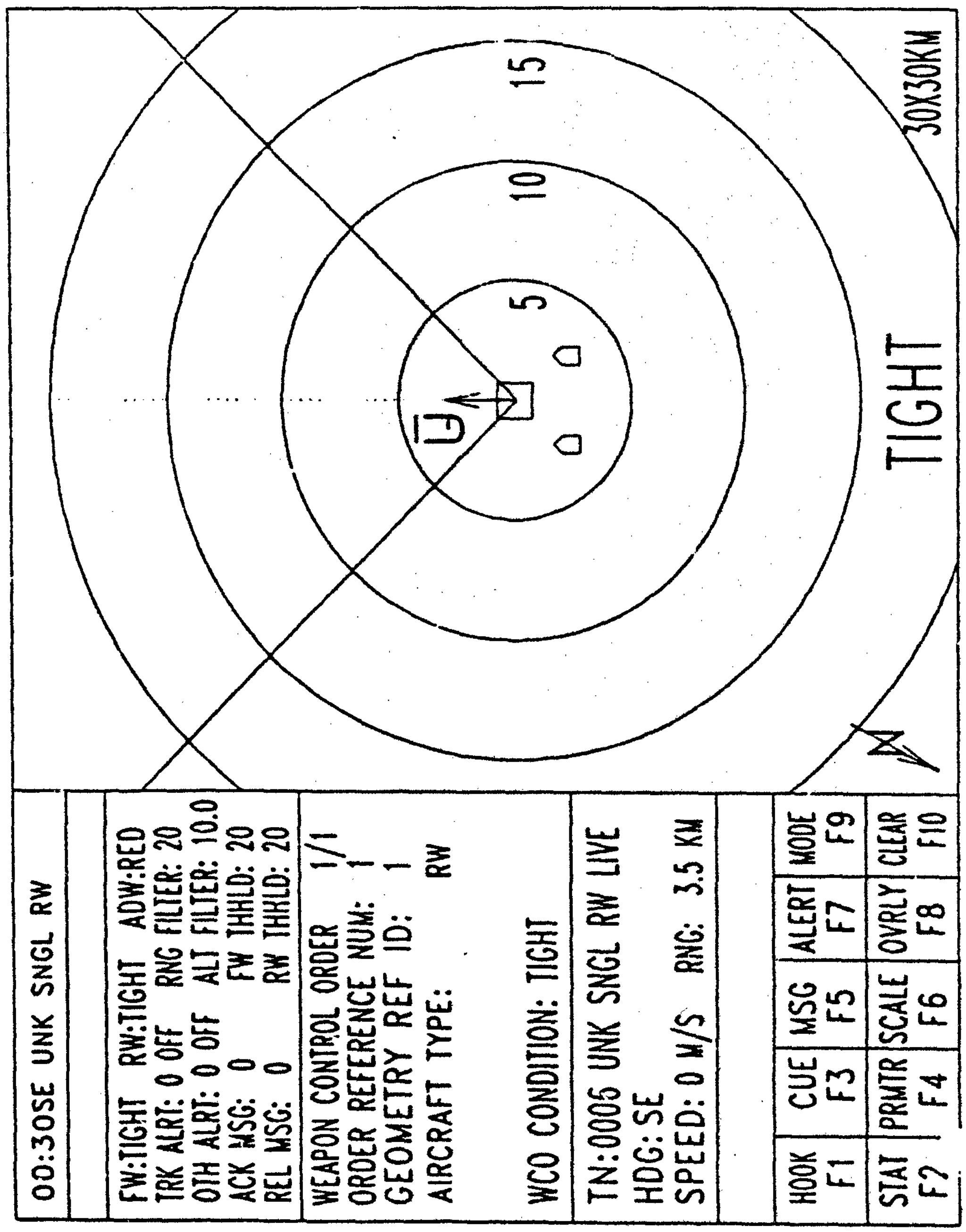

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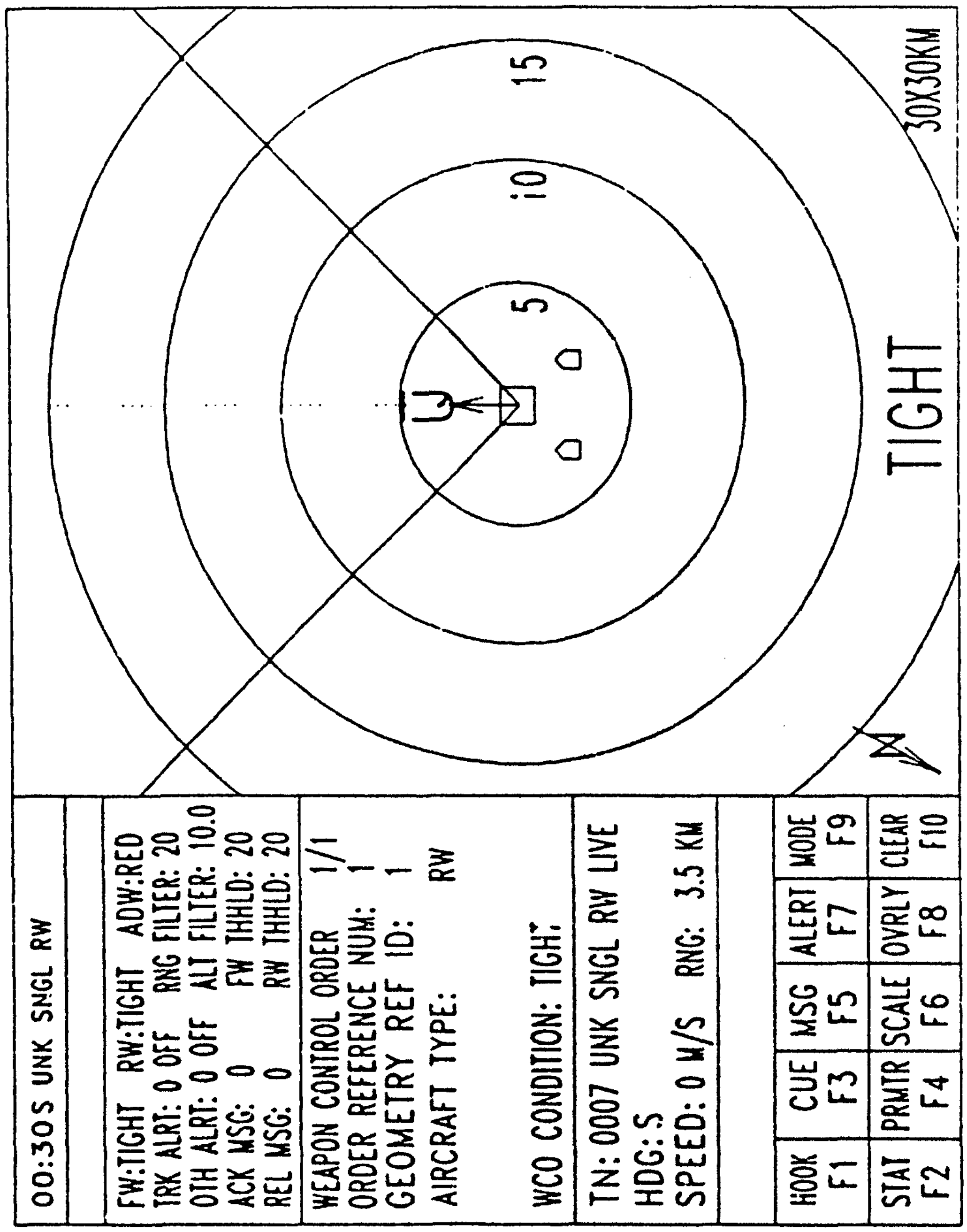

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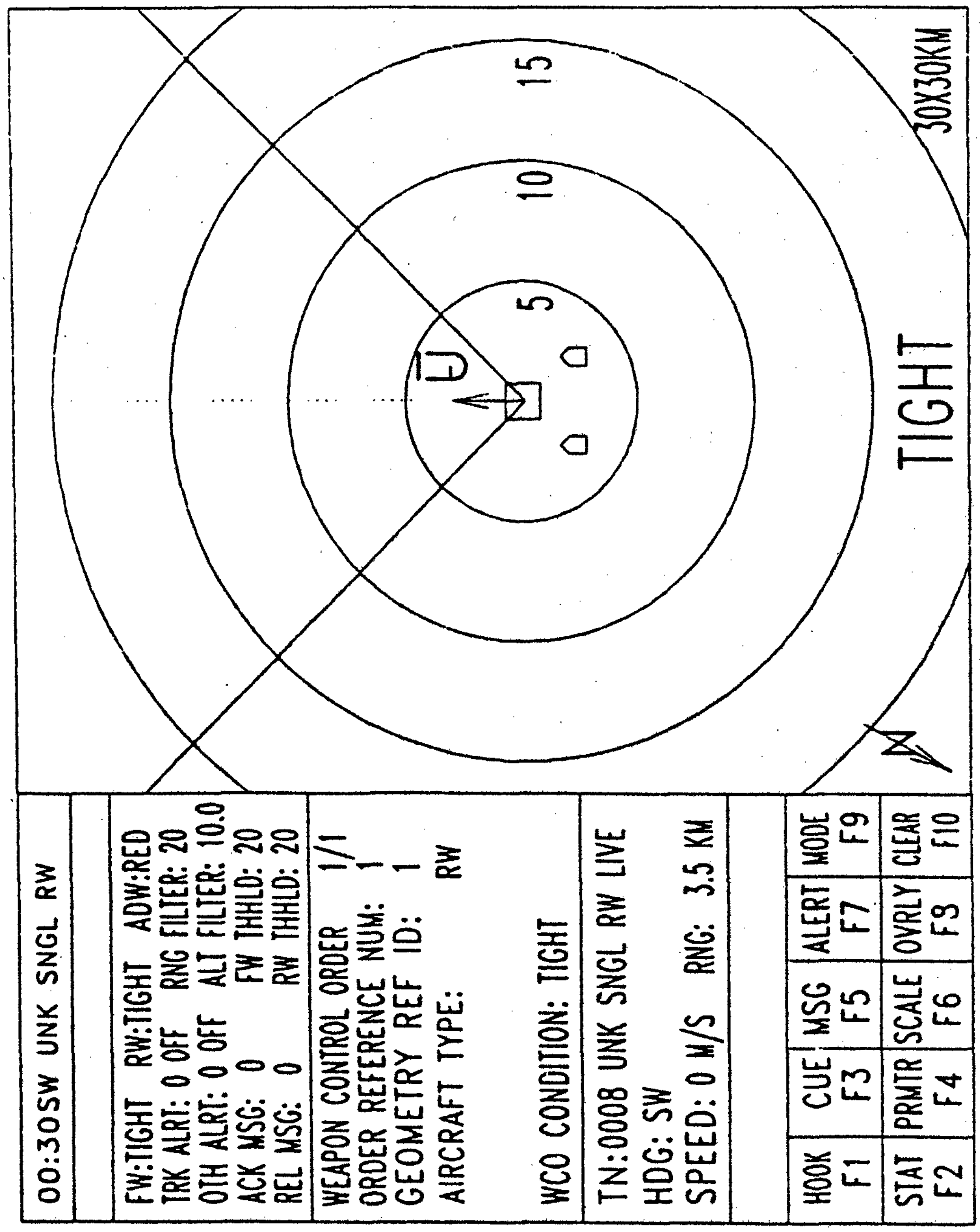

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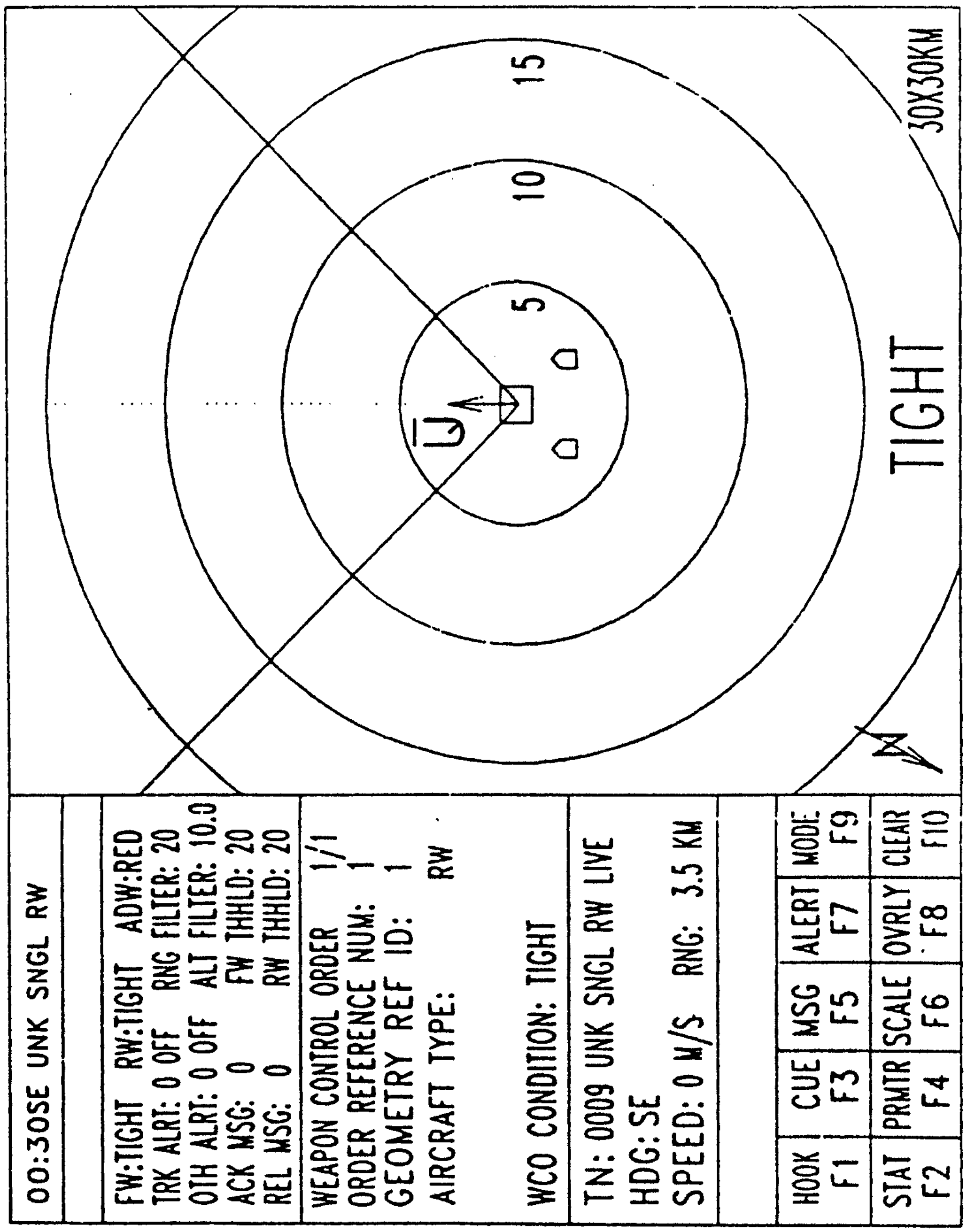

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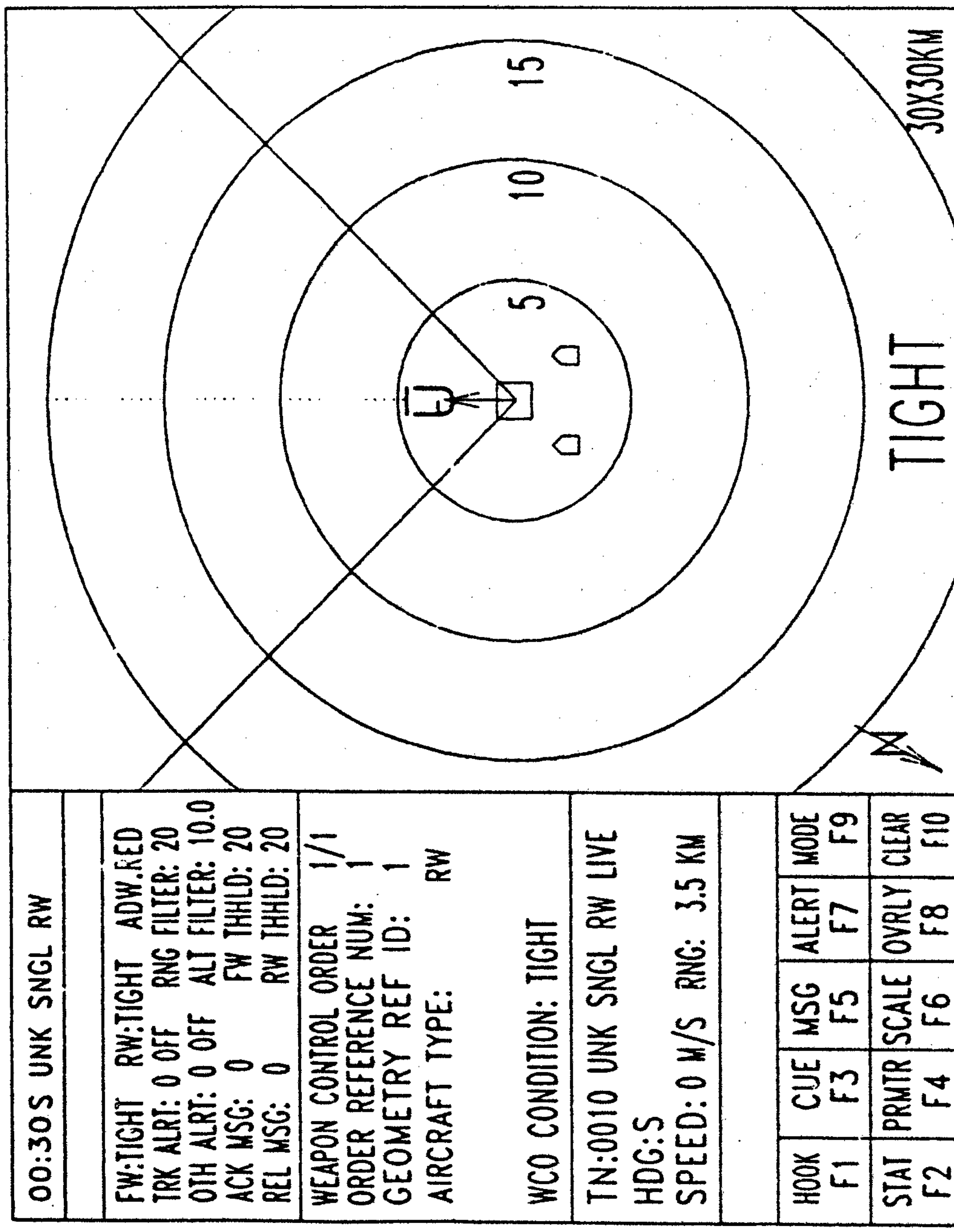
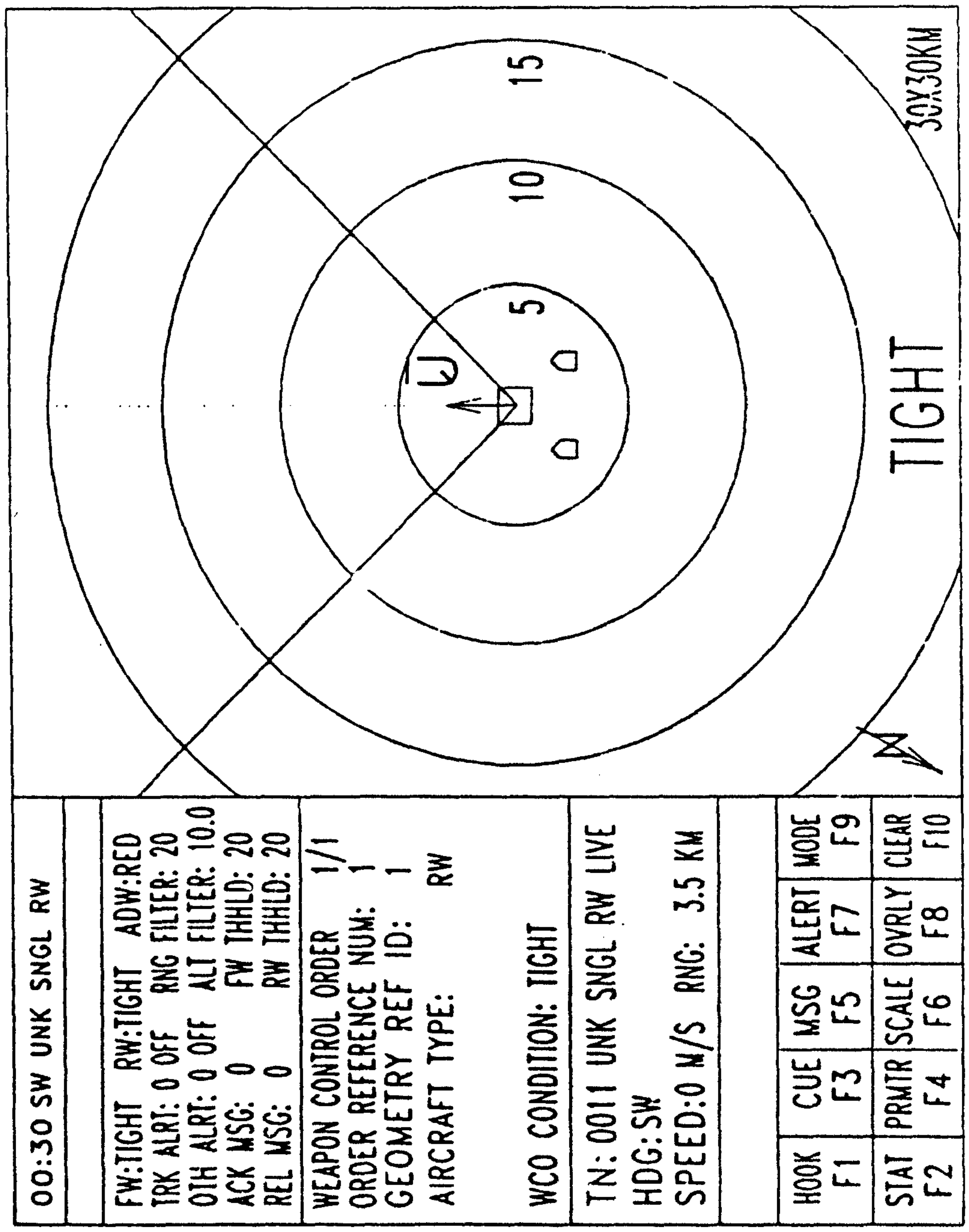


EHTU cue display for Scenario 10



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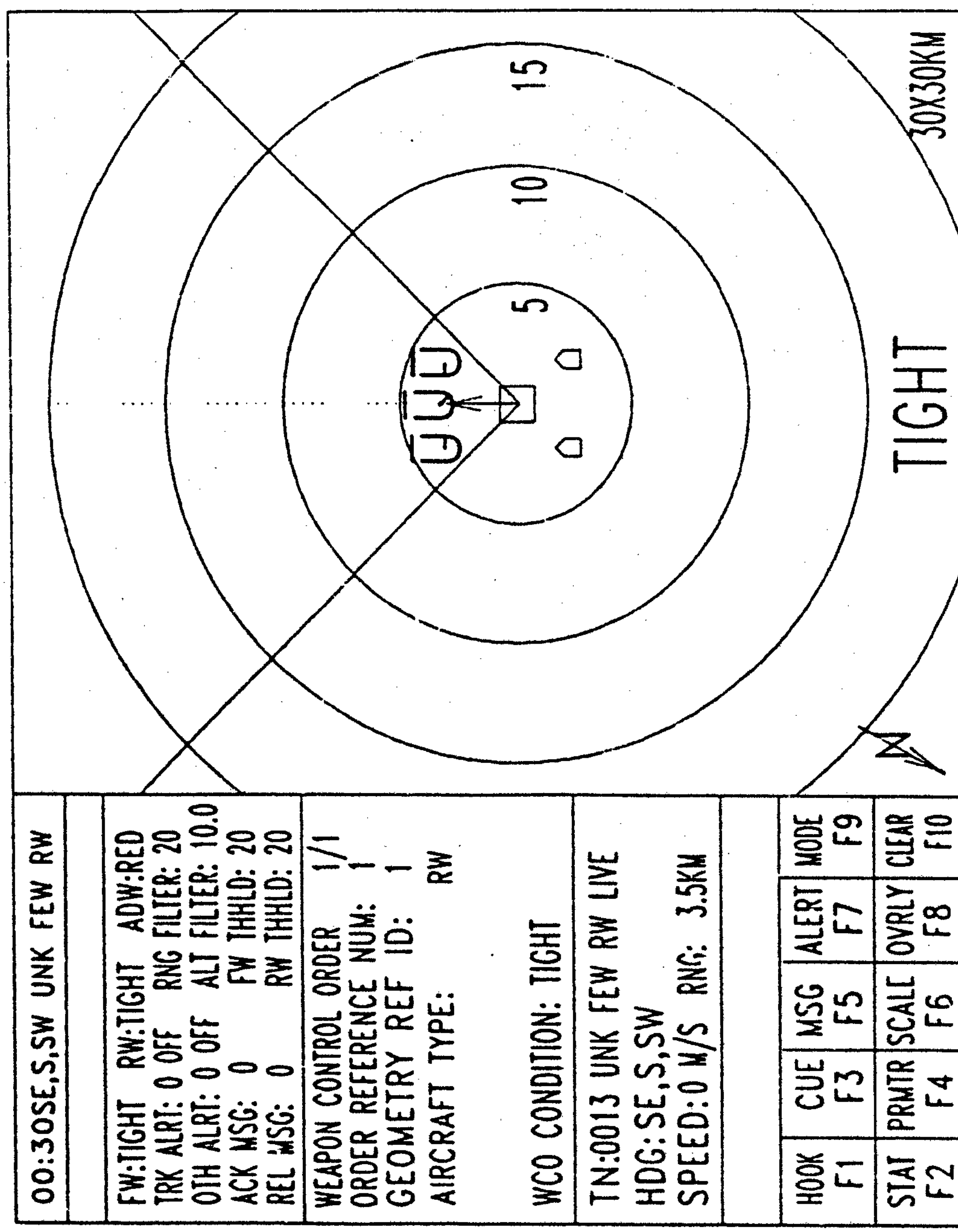
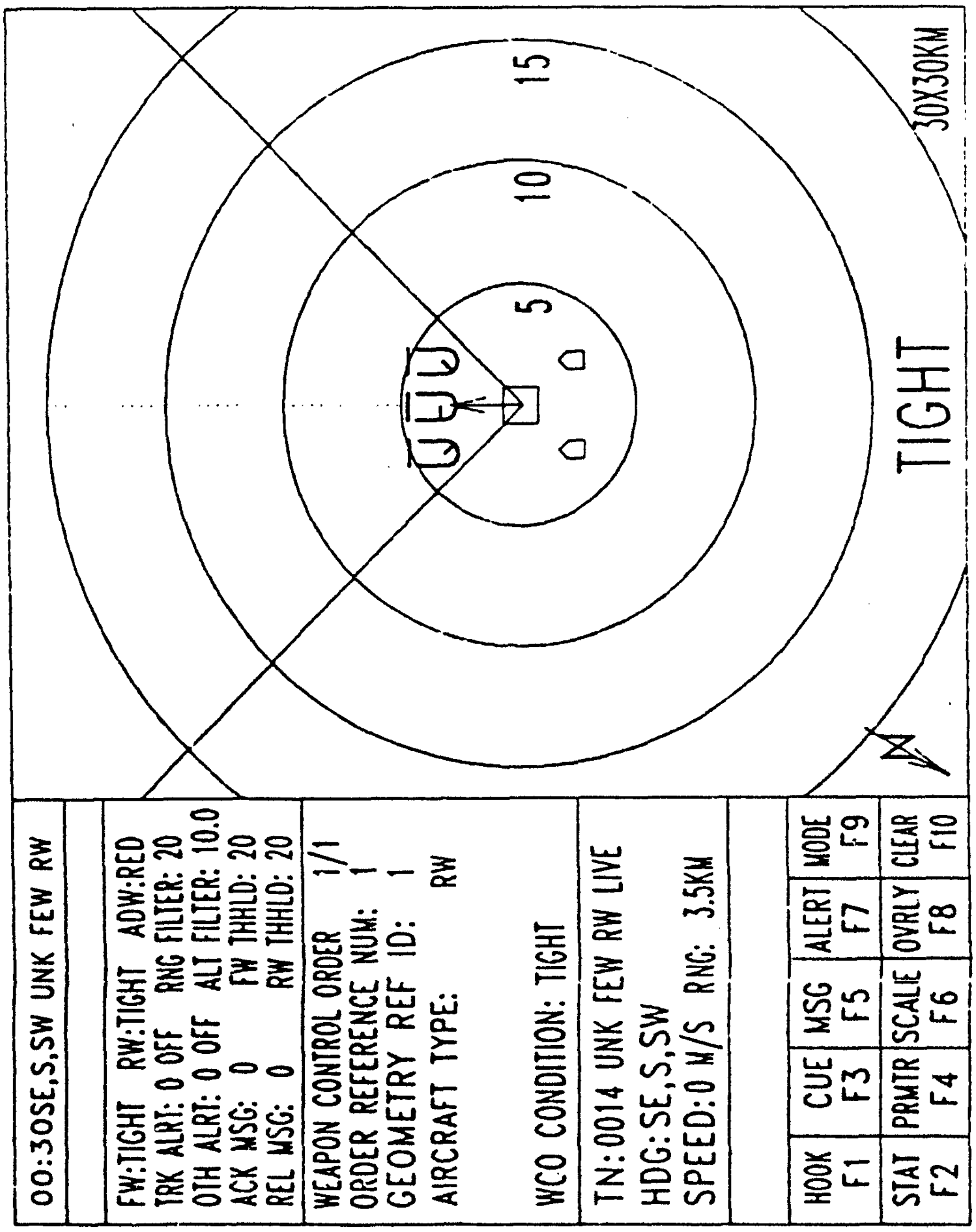


EHTU cue display for Scenario 12



EHTU cue display for Scenario 13

Appendix B

Performance Problems in MOPP4: Observations, Opinions of Soldiers, and "Work-Around" Solutions

M40 Mask And Hood

Problems using M19 binoculars with mask. All team chiefs interviewed (more than half were interviewed) reported problems using binoculars with the mask. They reported tunnel vision; double vision; visual disorientation; difficulty tracking moving aircraft with the small field of view available; cannot get the binoculars close enough to their eyes; eyepieces of binoculars slipped on surface of mask eyepieces. One of the authors experienced all of these problems when using the binoculars with the mask. The "work-around" solutions employed by team chiefs were to (1) close one eye; (2) close one eye and only look through one optic of the binoculars by turning them sideways; or (3) not use binoculars at all.

Problems using the Stinger sight with mask. All gunners interviewed (more than half were interviewed) reported problems using the Stinger sight with the mask. They reported difficulty tracking moving aircraft with the tiny field of view available; cannot get the sight close enough to their eyes; cannot see any (or cannot see all three, or cannot see right-most) superelevate and lead reticles in the Stinger sight. One of the authors experienced all of these problems when using the Stinger sight with the mask. The "work-around" solutions employed by gunners were to (1) manually estimate the appropriate superelevate and lead angles before firing; or (2) slip the mask slightly (breaking seal!) in order to see the superelevate and lead reticles.

Miscellaneous problem. Communication problems were observed for and reported by the Stinger teams—who stand literally right next to each other during an engagement and communicate directly without aid of field telephone or radio. The communication problems were not in reception with the mask and hood on (hearing) but in transmission with the mask and hood on. The mask distorted the sound of the voice. Soldiers experienced no difficulty whatsoever hearing and understanding USARI test personnel who were not speaking through a mask. One of the authors experienced this same problem when wearing the mask and hood. The "work-around" solution employed by soldiers was hand signals.

Gloves

Problem inserting IFF cable into gripstock of Stinger. Observed for all gunners initially. Problem solved with experience over trials.

Problem turning paper pages with gloved hands. Observed for all soldiers. All soldiers eventually learned the "work-around" solution of using the eraser of a pencil to turn pages.

Overgarment

Gunners' pants frequently came unsnapped from jacket and slipped down. No solution found.